AFIT/GTM/LAL/96S-6

A STUDY OF DEFENSE LOGISTICS AGENCY INVENTORY CLASSIFICATIONS: APPLICATION OF INVENTORY CONTROL METHODS TO REDUCE TOTAL VARIABLE COST AND STOCKAGE LEVELS

THESIS

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THESIS

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Abstract

This thesis analyzes the financial impact of applying a single inventory requirements model to three separate classes of inventory at the Defense Logistics Agency's (DLA) Defense Supply Center-Columbus (DSCC) commodity management facility. DLA's blanket application of its variation of the Economic Order Quantity (EOQ) requirements model may not be appropriate for all levels of demand, possibly suboptimizing DLA's desire to minimize inventory costs while still providing an appropriate level of customer service. Simulation analyses of the DLA EOQ requirements model, the Silver-Meal heuristic, and Periodic Order Quantity models were conducted to examine which dynamic lot-sizing model is more effective in minimizing inventory costs and levels for different levels of item demand. The Periodic Order Quantity model provided lower inventory levels and total variable costs than the DLA EOQ and the Silver-Meal models for the medium demand category. The DLA EOQ requirements model was found to provide lower inventory levels and total variable costs than either the POQ or the Silver-Meal models in the low and high demand categories.

A Study of Defense Logistics Agency Inventory Classifications:

Application of Inventory Control Methods to Reduce

Total Variable Cost and Stockage Levels

I. Background and Problem Presentation

Introduction

In recent years there has been increasing pressure on the federal government to reduce its size and hence, its expenditures of tax revenues. The government has responded in a variety of ways, including reorganizations, consolidations, downsizings, and reductions in all facets of the public sector. As one of the larger recipients of public moneys, the Department of Defense (DoD) has not escaped the axe wielded by government budget cutters. DoD senior leaders have had to make tough operational choices to balance the required level of mission readiness with the need for a smaller, more economical, yet effective military. The DoD's logistics system has emerged as a prime target for reductions and savings. Logistics managers throughout the DoD have been challenged to reduce inventories to save money.

The Defense Logistics Agency (DLA) is the largest provider of supplies in the DoD inventory system, managing over 3.8 million items valued at over $11 billion for the military services (DLA, 1996: 1). To improve management and visibility of its inventory, each of DLA's six commodity centers has established local procedures to facilitate the grouping and control of items assigned to their particular center. As an example, the Defense Supply Center - Columbus, Ohio (DSCC) has established

classifications based on the combination of: 1) an item's annual usage in dollars, and 2) the mission criticality of the part. Although each supply center uses a different classification method to group items, each DLA center uses the same economic order quantity (EOQ) inventory requirements model to determine reorder quantities for all items, regardless of classification. The "blanket" application of a single requirements model may not be appropriate for all classes, possibly suboptimizing DLA's desire to minimize inventory costs while still providing an appropriate level of customer service. This study will analyze the financial impact of applying a single inventory requirements model to separate classes of inventory at DLA's Defense Supply Center - Columbus commodity management facility.

Background

In 1961, after approximately 19 attempts to establish a civilian run supply agency to provide logistics support to the military departments, Secretary of Defense Robert McNamara announced the establishment of the Defense Supply Agency (DSA). The goal of this organization was to consolidate the 20 different numbering systems and 8 different item classifications that existed throughout the services at that time. On 1 October 1961, Lt. General Andrew T. McNamara was appointed as DSA's first director. General McNamara emphasized that the success of DSA would depend on the decentralization of the organization, delegation of authority to field commanders, procurement competition, simplification of the supply system, and standardization (Robinson, 1993: 3).

In 1977, DSA became the Defense Logistics Agency (DLA). DLA is headquartered in Alexandria, Virginia, and its mission is:

> ...to function as an integral element of the DoD logistics system and to provide effective and efficient worldwide logistics support to DoD components as well as to Federal Agencies, foreign governments, or international organizations as

> assigned in peace and war. (Its) vision ideally is to continually improve the combat readiness of America's fighting forces by providing soldiers, sailors, airmen, and marines the best value and services when and where needed. (Robinson, 1993: 6)

DLA is responsible for the management of over 3.8 million consumable items in support of the military services. The commodities managed by DLA include fuel, food, clothing, and medical supplies, as well as general supply items. In total, DLA is responsible for 86 percent of the consumable items required by the Air Force, Navy, Army, and Marine Corps (DLA Pamphlet, 1992: 2).

As these figures suggest, the scope of the inventory management responsibilities DLA faces is enormous, and they have responded to the challenge with an inventory management system that categorizes items based on physical characteristics and applications. These items are then assigned to one of six functional centers. These functional centers, listed in Table 1-1, provide total life-cycle item management, from acquisition to distribution to disposal.

Table 1-1. Commodity Assignment by DLA Center

Center	Location	Commodities Managed
Defense Supply Center-Columbus (West)	Dayton, OH	Electronics Items
Defense Fuels Supply Center	Ft. Belvoir, VA	Petroleum Products
Defense Supply Center-Richmond	Richmond, VA	General Supply Items
Defense Personnel Support Center	Philadelphia, PA	Personnel Support Items
Defense Supply Center-Columbus (East)	Columbus, OH	Construction Items
Defense Industrial Supply Center	Philadelphia, PA	Industrial Items

(Bilikam, 1996: Interview and notes)

This "macro" categorization of inventory allows for specialization and economies of scale in the areas of procurement, storage, and distribution within each commodity center. Because the number of items managed by each wholesale-level commodity center is still quite large, a further classification of inventory is both necessary and beneficial.

Inventory Classification and Categorization

Inventory can be classified into groups to allow for an appropriate level of control over items in the groups. Detailed, or increased, inventory control of an item is costly and it is usually uneconomical to apply detailed control on all items in an inventory (Tersine & Campbell, 1977: 162). Some items require increased control or visibility due to characteristics such as usage, value, or criticality.

Critical items are defined as those assets that are crucial to the operation of the firm. The lack of these items when required could result in the shutdown of production lines or the permanent loss of future sales due to the deterioration of customer goodwill. From a military standpoint, critical items are necessary to maintain weapons systems (i.e. aircraft, tanks, ships, etc.) in a fully operational status.

One classification scheme that separates inventory into distinct classes based on all three of the above characteristics is the ABC classification method. The ABC method is based on a concept attributed to Vilfredo Pareto known as the “Pareto Principle.” In essence, the Pareto Principle states that many situations are dominated by a relatively vital few elements (Magad & Amos, 1989: 123). The ABC classification scheme is an inventory application of the Pareto Principle and states that whenever inventory is held, a large percentage of the dollar investment in stock is concentrated on relatively few items (Ammer, 1980: 288). The figures vary from text to text, but it is generally acknowledged that between 10 and 20 percent of the items held in inventory will account for 80 to 90 percent of the annual usage dollar value of the inventory. These 10-20 percent high value items are categorized as class “A." Management decides the appropriate placement of the remainder of the items, either in categories “B” or “C” depending on their value and operational criticality. Table 1-2 lists the three categories of the ABC classification method:

Table 1-2. ABC Inventory Classifications

Classification	Description
A	Items with high demand/large unit value
B	Items with low demand or small unit value
C	Items with low demand and small unit value

By segregating inventory in this fashion, firms can focus their attention on the small group of class "A" items that account for the highest annual dollar volume (number of items demanded multiplied by unit value) and which absorb most of the inventory budget. These items are given careful consideration when forecasting, planning, and controlling inventories because they offer the potential for greater financial benefits if managed properly. Small or no savings can be expected from optimizing the control of "B" and "C" items (Petrovic, Senborn & Vujosevic, 1986: 12-13). Because of the extraordinary number of items stocked and its desire to minimize inventory control costs, DLA uses the ABC inventory classification system to effectively manage inventories at its commodity centers

Each DLA center commander is given authority to apply a customized version of the ABC inventory classification method most appropriate for the types of items managed by the center under their command. As mentioned in the introduction, this study will evaluate the Defense Supply Center-Columbus (DSCC) as the representative DLA commodity center. The DSCC commander has chosen a variation of the ABC method that classifies items based on a combination of the following item characteristics:

1. Annual Demand Frequency (ADF). The number of orders or requisitions received by DSCC in one year for a specific inventory item.
2. Annual Demand Value (ADV). The unit price of an item multiplied by the total quantity demanded in one year.
3. Weapon System Group (Criticality) Code (WSGC). The military services provide this code to DLA for each National Stock Number (NSN) based upon

the operational criticality of the weapon system that particular item supports. This code allows prioritization of item requirements received by DLA (see Table 1-3 below):

Table 1-3. Weapon System Group (Criticality) Code (WSGC)

WSGC	Criticality
A	Most Critical
B	Critical
C	Least Critical

4. Weapon System Essentiality Code (WSEC). This code indicates the importance of the demand as it affects the operational capability of a specific piece of equipment or weapon system (see Table 1-4 below):

Table 1-4. Weapon System Essentiality Code (WSEC)

WSEC	Essentiality
1	Mission Essential - Failure of item will render end item inoperable.
3	Non-mission Essential - Failure of item will not render end item inoperable.
5	Mission Degrading - Item is needed for personal safety.
6	Mission Degrading - Item is needed for legal, climactic or other requirements peculiar to the planned operational environment of the end item.
7	Mission Degrading - Item is needed to prevent impairment of or the temporary reduction of operational effectiveness of the end item.

5. Weapon System Indicator Code (WSIC). Single digit alpha code assigned by DSCC based on the demanded item's WSGC and WSEC (see Table 1-5 below):

Table 1-5. Weapon System Indicator Code (WSIC) Matrix

WSIC	WSGC	WSEC	WSIC	WSGC	WSEC	WSIC	WSGC	WSEC
F	A	1	H	A	6	K	A	3 or blank
L	B	1	P	B	6	S	B	3 or blank
T	C	1	X	C	6	Z	C	3 or blank
G	A	5	J	A	7	N	N/A	N/A
M	B	5	R	B	7			
W	C	5	Y	C	7			

Based upon the five classification criteria listed above, DLA prioritizes inventory categories by assigning a single digit numeric code referred to as the Selective Management Category Code (SMCC). After assignment of the SMCC, DSCC assigns a Band code to each inventory item, representing its version of the ABC classification method. The Band code is used by DSCC to assign priorities for individual item control. The Band/SMCC matrix is presented in Table 1-6 as follows:

Table 1-6. Band/SMCC Matrix

BAND	SMCC	ADF	ADV	WSIC	WSGC	WSEC
A	1	150+	>$7000	F,G,H,J,K,L,M,P,R,S,T,W,X,Y,Z,N	A,B,C	1,5,6,7,3, Blank
A	2	150+	<=$7000	F,G,H,J,K,L,M,P,R,S,T,W,X,Y,Z,N	A,B,C	1,5,6,7,3, Blank
A	3	20-149	>$7000	F,G,H,J,K,L,M,P,R,S,T,W,X,Y,Z,N	A,B,C	1,5,6,7,3, Blank
A	4	20-149	<=$7000	F,G,H,J,K,L,M,P,R,S,T,W,X,Y,Z,N	A,B,C	1,5,6,7,3, Blank
A	5	4-19	>$7000	F,G,H,J,K L,T	A B,C	1,5,6,7,3, Blank 1
A	6	4-19	<=$7000	F,G,H,J,K L,T	A B,C	1,5,6,7,3, Blank 1
B	7	4-19	>$7000	M,P,R,S,W,X,Y,Z,N	B,C	5,6,7,3, Blank
B	8	4-19	<=$7000	M,P,R,S,W,X,Y,Z,N	B,C	5,6,7,3, Blank
C	9	0-3	>$7000	F,G,H,J,K,L,M,P,R,S,T,W,X,Y,Z,N	A,B,C	1,5,6,7,3, Blank
C	0	0-3	<=$7000	F,G,H,J,K,L,M,P,R,S,T,W,X,Y,Z,N	A,B,C	1,5,6,7,3, Blank

The above inventory classification scheme gives DSCC managers visibility on the critical few items that comprise the bulk of their inventory investment. This visibility can be a vital tool when procurement decisions must be made, decisions that attempt to maximize the use of available capital resources and satisfy mission requirements, while minimizing the costs associated with ordering and holding inventory.

Problem Statement

DSCC may be sub-optimizing by using a single inventory requirements model to determine order quantities for the different classes of inventory it manages. The research question that will be addressed is:

Do different dynamic lot sizing models, when applied to the existing DSCC classification structure, provide lower total variable costs and inventory levels than the DLA EOQ requirements model?

Investigative Questions

The following investigative questions will be addressed to provide relevant answers to the research question:

1. What are the results, in terms of costs and inventory levels, of applying the DLA EOQ requirements model, the Silver-Meal Heuristic, and the Periodic Order Quantity model to low, medium, and high demand items?
2. Which inventory model, the DLA EOQ requirements model, the Silver-Meal Heuristic, or the Periodic Order Quantity model is more effective in minimizing inventory costs and levels for low, medium, and high demand items?

These questions will provide answers as to the effectiveness of the DLA inventory requirements model, as compared to two other inventory models, the Silver-Meal heuristic and the Periodic Order Quantity model.

Research Approach

The specific research steps that will be accomplished are:

1. Gather and adjust data from the Defense Supply Center-Columbus (DSCC) to provide a database to evaluate the effects of different inventory models on different classifications of inventory at DSCC.
2. Perform simulations of order-point, order-quantity (s, Q) consumable inventory models, the DLA EOQ requirements model, the Silver-Meal heuristic, and the Periodic Order Quantity model on different SMCC classifications of inventory to determine the impact the different models have on total variable costs and computed inventory levels.
3. Statistically determine if differences in the resulting cost and inventory figures from the simulations are significant.
4. Determine which model is most effective at minimizing DSCC's total variable costs and inventory levels for each type of demand; low, medium, and high.

Methodology

The tool used to accomplish the research objectives and answer the research question will be simulation. Simulation is preferable to analytic models because of the flexibility it offers when analyzing complex inventory problems. Simulation models for the DLA EOQ requirements model, the Silver-Meal heuristic, and the Periodic Order Quantity will be developed to measure on-hand inventory and total variable costs realized by the respective ordering schemes. Real-world data from each of DSCC's inventory classes will be statistically analyzed to provide accurate order frequency and order quantity input to the models. Simulation output from the three models will then be statistically compared to determine which inventory model is most effective at minimizing costs and inventory levels for different SMCC classifications.

Scope and Limitations

1. Due to time and budgetary limitations, research will be limited to items managed by DSCC. DLA must determine if results are applicable to their entire inventory management system.
2. DLA's inventory forecasting model will be not be evaluated in this study. The forecasting method used will approximate the Naive Forecast 1 technique where actual demand from the past period serves as the forecasted demand for the present period. In-depth evaluation of the forecasting method is beyond the scope of this research.
3. Three of DLA's ten SMCC classifications will be simulated. These three classifications will represent high, medium, and low demand items as determined by DSCC's Band/SMCC matrix (see Table 1-6). Specifically, high demand items are those with 150 or more demands per year, medium demand items have between 4 and 149 demands annually, and low demand items experience fewer than 4 annual demands.
4. Analysis of the inventory ordering schemes will be limited to quantifiable costs incurred in the operation of an inventory system. Factors such as customer service levels and issue effectiveness are beyond the scope of this study.

Organization of Thesis

Chapter I has provided an introduction to the issues surrounding DLA's inventory management system. Background information has been provided to assist the reader in understanding the potential for total variable cost and inventory level reductions through application of a different inventory model to the different classes of inventory managed by DSCC. Chapter II will provide a review of literature relevant to the problem.

Chapter III will describe, in detail, the inventory models selected for evaluation. Chapter IV describes the methodological approach used to assist in evaluating the effectiveness of the different inventory models. This chapter will further discuss the concept and application of simulation as a research tool. Data obtained from model simulations will be analyzed and discussed in Chapter V. This will include the type of data obtained and the analytical methods used to test the proposed hypotheses. Chapter VI will contain the results of the analyses conducted in Chapter V. The investigative questions posed in Chapter I will be addressed. The overall conclusion as to the effectiveness of applying DLA’s requirements model to all classes of inventory held will be provided, and additional areas of exploration for follow-on study will be suggested.

II. Literature Review

Introduction

This chapter will explore various concepts governing consumable item management. Specifically, it will provide the framework for an understanding of the importance of total variable costs and inventory levels as measures for evaluating the effectiveness of inventory requirements models when applied to DLA's inventory classifications. First, this chapter will define inventory, explain why stocks are held, and explore the evolution of contemporary views towards the accumulation of inventory. Next, inventory costs will be discussed, followed by an examination of continuous review inventory systems, with emphasis on the continuous review order-point, order-quantity (*s*, Q) system currently used by DLA. Then, inventory demand patterns and their impact on the calculation of reorder quantities will be presented. Finally, previous research that has contributed to this study will be reviewed.

What is inventory?

"Very basically, inventory is required to satisfy demand" (Heilweil, 1986: 52). Stephen F. Love defines inventory as "a quantity of goods or materials in the control of an enterprise and held for a time in a relatively idle or unproductive state, awaiting its intended use or sale" (1979: 3). In addition, Waters has further defined the difference between stock and inventory. "Stock consists of all the goods and materials stored by an organization. It is a supply of items which is kept for future use. Inventory is a list of the items held in stock" (1992: 4). Stock acts as a buffer between supply and demand, allowing operations to continue smoothly when the supply rate does not exactly match

the demand rate (Waters, 1992: 7). The major reason organizations hold stocks is to ensure that a supply of an item will be available when it is needed (Barrett, 1969: 1).

Tersine states that "inventory exists because organizations cannot function without it" (1982: 9). He further adds that inventory is held in a inactive or unproductive state awaiting utilization for its intended purpose. Why inventory is held can be explained by four functional factors: 1) time, 2) discontinuity, 3) uncertainty and, 4) economy (Tersine, 1982: 6). These functional factors are summarized in Table 2-1 as follows:

Table 2-1. Inventory Functional Factors

Functional Factor	Why Inventory is Held	Benefits of Holding Inventory
Time	For production and distribution processes required before delivery to final consumers	- Decreases or eliminates consumer purchase waiting times - Firms can reduce lead times to satisfy demand
Discontinuity	To treat retailing, distributing, warehousing, manufacturing, and purchasing as independent operations	- Production is not geared directly to consumption - Consumption is not forced to adapt to production - Firms can schedule operations more efficiently
Uncertainty	To adjust to unforeseen events that alter organizational plans	- Protects the firm from unanticipated or unplanned circumstances
Economy	To allow the firm to take advantage of cost reduction opportunities	- Enable the firm to purchase or produce items in economic quantities - Make bulk purchases with quantity discounts - Smooth production and manpower requirements for seasonal items

(Tersine, 1982: 9-10)

Complementing Tersine's four functional factors of inventory are Waters' reasons for holding inventory as listed in Table 2-2:

Table 2-2. Reasons for Holding Inventory

- to act as a buffer between different operations
- to allow for mismatches between supply and demand rates
- to allow for demands which are larger than expected, or at unexpected times
- to allow for deliveries which are delayed or too small
- to avoid delays in passing products to customers
- to take advantage of price discounts on large orders
- to buy items when the price is low and expected to rise
- to buy items which are going out of production or are difficult to find
- to make full loads and reduce transport costs
- to provide cover for emergencies
- to maintain stable levels of operations

(Waters, 1992: 7)

Historical Views of Inventory

In the 1600s, inventory was perceived as a measure of wealth. Individuals would collect and hold as much stock as possible because production and distribution of any commodity (supply) was uncertain. However, at the turn of the 20th century, supplies were no longer uncertain in the industrialized world. Consumers or manufacturers did not have to buy goods as soon as they were available. Rather, they could wait until items were needed before procurement (Waters, 1992: 23-24). In their book Decision Systems for Inventory Management and Production Planning, Silver and Peterson point out that inventories today represent large potential risk and are not seen as a measure of wealth. They further state that corporate policy makers fear items held over and above actual needs may become obsolete and will require disposal at considerable financial loss (1985: 4). According to Tersine, there is an optimum level of inventory investment. Having an excessive amount of inventory can impair corporate profits as much as having too little inventory. "With inventories, too much can result in unnecessary holding costs, and too little can result in lost sales or disrupted production. An organization must be careful not to over-invest in inventory that ties up capital and may become obsolete, yet it must take care not to run out of materials (thus idling people and equipment) or

products (thus losing sales and customers)” (Tersine, 1982: 10). To combat the accumulation of excess inventories, firms now use “scientific inventory control” methods. These methods include sophisticated models and mathematical analyses to set optimal stock levels based on individual circumstances (Waters, 1992: 24). This study will focus on scientific inventory control methods that compute reorder quantities using a continuous review inventory system.

Continuous Review Inventory Systems

The DoD presently uses a continuous review inventory system to manage wholesale and retail spares and repair parts (Perry, 1991: 1). Under this system, the inventory or stock status is always known. The continuous review system immediately updates an individual item’s inventory status at the time a transaction such as an issue, receipt, or shipment is processed. In contrast, periodic review inventory systems determine the inventory status of stocked items at fixed time intervals (Silver & Peterson, 1985: 255). Continuous review systems use the reorder point to signal the need for a stock replenishment and the order quantity to determine how much to reorder. Order quantities are usually based on procurement ordering cost and inventory holding cost trade-offs. These trade-offs lead most firms to reorder a replenishment quantity, known as the economic order quantity (EOQ), that balances ordering and holding costs to minimize total variable costs (Perry, 1991: 1).

The greatest advantage of continuous review as compared to periodic review inventory systems is the decreased amount of safety stock required under the continuous review system. “This is because the period over which safety protection is required is longer under periodic review (the stock level has the opportunity to drop appreciably between review instants without any reordering action being possible in the interim)”

(Silver & Peterson, 1985: 255). The continuous review inventory system employed by DLA is the order-point, order-quantity (s, Q) system (Perry, 1991: 1).

Order-Point, Order-Quantity (*s, Q*) System

Under the *s, Q* inventory system, a fixed order quantity (*Q*) (usually the EOQ) is ordered after the inventory position has fallen to the reorder point or safety level (*s*) or lower. This system is illustrated by a sawtooth diagram in Figure 2-1 as follows:

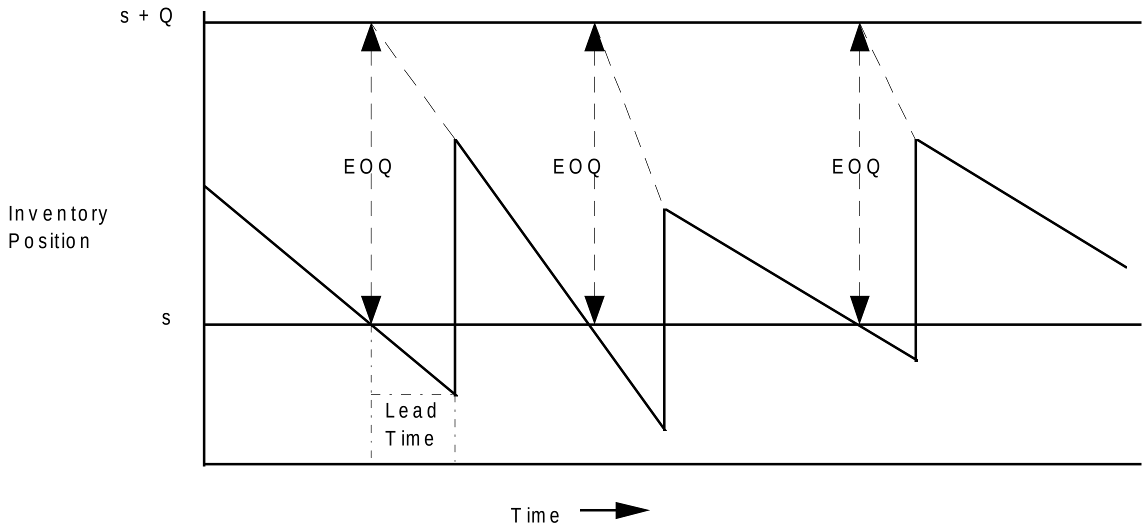

Figure 2-1. Order-Point, Order-Quantity (*s, Q*) System

(Plossl & Wight, 1967: 97)

In the *s, Q* system, the inventory position and not the quantity of stock in the warehouse is used to initiate a replenishment order. The inventory position is used because it includes the stock already on order but not yet received, eliminating the possibility of placing a duplicate order before the first order is received. (Silver & Peterson, 1985: 256). Figure 2-1 illustrates that at some point in time, the inventory position of an item will fall to the reorder point *s* and trigger a replacement order for the EOQ to raise the inventory level to *Q*. The inventory level will continue to fall during

the lead time (the time that elapses from the moment a replenishment order is placed until the order is received into stock and is ready for use). Once the order is received, the inventory position is increased by the EOQ, starting the cycle once again (Plossl & Wight, 1967: 96).

Demand Patterns

Firms that sell goods experience varying demand patterns from their customers. Determination of the type of demand an item experiences is crucial in the computation of reorder quantities by inventory managers. Demand for goods held in inventory follows either a deterministic (constant) or probabilistic (variable) demand pattern. The simplest case of demand encountered by a company is deterministic, characterized by demand for stocked items that is known in advance with certainty over a finite period. Inventory systems based on deterministic demand are relatively uncomplicated to manage because firms are not required to forecast for varying and uncertain inventory requirements. However, it is uncommon for firms to experience deterministic demand for their products in the real world. In reality, the typical demand pattern experienced by most firms in the business environment is probabilistic, or random.

Probabilistic demand is often characterized by erratic demand patterns and requires that inventory managers rely on sound forecasting techniques to aid in the computation of order quantities which minimize inventory ordering and holding costs. Lumpy demand, as defined by Peckham, is a special case of erratic demand often found among low-volume, slow-moving items. These items show many periods with zero demand, a low-average demand, and occasional demands which may be five or ten times the average (Peckham, 1972: 48). In order to analytically calculate whether demand is considered lumpy, Silver and Peterson have proposed the Variability Coefficient (VC) measure, which is denoted as follows:

$$VC = \frac{\text{Variance of demand per period}}{\text{Square of average demand per period}}$$

(Silver & Peterson, 1985: 238)

If the value of VC is less than 0.2, the demand for the item is considered constant and continuous (deterministic). If the VC is greater than or equal to 0.2, the demand pattern is classified as lumpy. Lumpy demand for items makes it difficult for inventory managers to calculate reorder quantities because customer demand cannot be predicted with certainty. Too little inventory ordered may result in lost sales and customer dissatisfaction while too much inventory ordered will unnecessarily increase inventory costs.

Inventory Costs

Every firm that stores inventory incurs certain costs in the operation of an inventory management system. Silver and Peterson list five relevant costs associated with inventory. They are the unit value or unit variable cost, the cost of carrying items in inventory, ordering costs, shortage costs, and system control costs (1985: 62-64).

The unit value or variable cost is also referred to as the purchase price plus freight charges if the item is obtained from an external source. If the item is produced internally, its value equals the unit production cost. Tersine states that "for purchased items, it is the purchase price plus any freight cost. For manufactured items, the unit cost includes direct labor, direct material, and factory overhead" (1982: 16).

Carrying or holding costs are the costs of holding one unit of an item in stock for one unit of time. These costs include: 1) the opportunity cost of the money invested, 2) the expenses incurred in running a warehouse, 3) the cost of special storage requirements, 4) deterioration of stocks, 5) obsolescence, and 6) insurance and taxes (Silver & Peterson, 1985: 62). DSCC's annual holding cost is 10 percent.

Ordering costs, according to Waters, consist of the costs incurred during order placement and can include computer time, quality checks, correspondence, delivery, telephone costs, expediting, use of equipment, and receiving (1992: 36). DSCC applies a cost of $5.20 per order placed with its suppliers.

Shortage costs, also known as stockout costs, result when an item is not available to fill a customer's order. These costs are incurred as the company initiates an expedited order to obtain the item as a backorder. The backorder can result in increased transportation costs, handling costs, and special shipping and packaging costs. Shortage costs can also include lost sales and loss of customer goodwill if the customer is not willing to wait for the firm to receive the backorder. Lost sales result in reduced revenue to the firm while a goodwill loss amounts to customers not returning to purchase additional items in the future (Tersine, 1982: 17).

System control costs result from the firm's implementation of specific inventory control systems. Included in this category are the costs of data acquisition, data storage, computation, and employee training (Silver & Peterson, 1985: 64).

The costs incurred through the management of an inventory system are a necessary evil of doing business. However, to remain competitive, firms must ensure they adopt a system that minimizes inventory costs while providing a management-specified level of customer service.

Related Studies

Long and Engberson studied the effect of violations of the assumption of constant demand on the DLA EOQ model. They collected data on 540 stock numbered items managed by DLA and established a factorial design experiment with total variable cost, average on hand inventory, and pre-replenishment inventory as response variables. The response variables were designed to measure the effect of non-continuous or lumpy

demand on inventory costs. The factors established by the researchers were: 1) demand pattern, 2) annual demand, and 3) lead time. Each factor contained three levels of treatments.

Using the collected stock number data as input parameters, Long and Engberson conducted numerous simulation runs of DLA's EOQ formula. An analysis of the simulation output revealed that the variances between treatment means were not equal and independence was not achieved between simulation runs. As a result, Long and Engberson were unable to use statistical tools to determine the effect of lumpy demand on the EOQ model used by DLA and instead made practical observations on the output data. The researchers concluded that lumpy demand caused average on hand inventory to greatly fluctuate and required higher levels of safety stock. In addition, they determined that lumpy demand varies the on-hand balances of stocked items, negatively impacting customer support.

Berry and Tatge extended the research of Long and Engberson by evaluating the overall suitability of the DLA EOQ model. Specifically, the purpose of their study was to ascertain the overall impact of lumpy demand on DLA's model and determine if a better inventory model could be used in place of DLA's current requirements model. To quantify the effects of lumpy demand, Berry and Tatge identified two performance measurements: total variable cost and average on-hand inventory. They postulated that if total variable costs differed substantially under lumpy demand, this would demonstrate that variable demand impacted DLA's model greatly. Furthermore, if the average on-hand inventory under lumpy demand differed significantly than under constant demand, given that annual demand is the same under both conditions, then lumpy demand would impact DLA's model (Berry & Tatge, 1995: 3-3).

The researchers collected data on 525 national stock numbered items from DLA and simulated DLA's EOQ model under the three following demand conditions: 1)

constant and continuous, 2) normal, and 3) lumpy. Berry and Tatge also simulated the Silver-Meal model under lumpy demand conditions to determine if this model handles lumpy demand conditions better than DLA's current requirements model. Their simulation models incorporated the DLA quarterly forecasting model, a simple exponential smoothing method which provided the demand projections required to run the models.

Based upon their statistical analyses, Berry and Tatge determined that DLA's assumption of constant demand causes DLA to maintain higher inventory levels and that lumpy demand causes DLA to incur greater total variable costs. They discovered that average on-hand inventory and total variable costs increase from the constant and continuous model to the normal model and from the normal model to the lumpy model. Based upon these results, Berry and Tatge concluded that the DLA model "is not robust enough to handle lumpy demand patterns" (Berry & Tatge, 1995: 5-2). In addition, they discovered that the Silver-Meal model provided lower average inventory levels and lower total variable costs than the current DLA EOQ model. This finding suggests that other models exist that better handle lumpy demand patterns than the DLA EOQ model (Berry & Tatge, 1995: 5-3).

Summary

This chapter has provided the necessary background to understand the significance of this research. Topics covered included a definition of inventory and the reasons why stocks are held. Continuous review inventory systems were described, with an emphasis on the order-point, order-quantity (s, Q) system. Next, inventory costs were discussed, followed by an examination of inventory demand patterns and their impact on the calculation of reorder quantities. Finally, previous research that has contributed to this study was reviewed. The next chapter will discuss DLA's current EOQ requirements

model and two models that can be used in lieu of the EOQ, the Silver-Meal heuristic and the Periodic Order Quantity model.

III. Continuous Review Inventory Models

Introduction

This chapter will explore the Economic Order Quantity (EOQ), the Periodic Order Quantity (POQ), and the Silver-Meal heuristic. The basic arithmetic equations of the three models will be presented followed by a discussion of the demand conditions that favor the application of each model. In addition, the advantages and disadvantages of each model will be examined. The EOQ and POQ models and the Silver-Meal heuristic will be simulated with DLA demand data in this study, as will be discussed in Chapter IV. As such, an overview of each model is required to more fully comprehend the simulation results.

EOQ Model

One of the scientific inventory models that serves as the foundation for much of inventory theory is the classic Economic Order Quantity (EOQ). Waters describes the EOQ model as “the most important analysis of inventory control, and arguably one of the most important results derived in any area of operations management” (1992: 32). Credit for the development of the EOQ model is often given to Wilson who marketed the results of his research in the 1930s. However, the actual originator of the EOQ model was Ford Whitman Harris who published his discovery in 1913 in a journal entitled Factory, The Magazine of Management (Erlenkotter, 1990: 937).

The EOQ formula shown below represents a deterministic inventory model which minimizes total relevant costs by balancing inventory holding costs with ordering costs.

$$EOQ = \sqrt{\frac{2AD}{vr}}$$

Where:

A = Fixed cost component incurred with each replenishment ($)
D = Demand rate of the item (in units/unit time)
v = Unit variable cost of the item ($/unit)
r = Carrying charge ($/$/unit time)

(Silver & Peterson, 1985: 175-176)

The basic EOQ model is subject to the eight assumptions listed in Table 3-1. Although the assumptions may appear severe, one must consider the fact that the classic EOQ model is a simplification of reality.

Table 3-1. EOQ Assumptions

1. A single item is considered.
2. All costs are known exactly and do not vary.
3. No shortages are allowed.
4. Lead time is zero (so a delivery is made as soon as the order is placed).
5. Purchase price and reorder costs do not vary with the quantity ordered.
6. A single delivery is made for each order.
7. Replenishment is instantaneous so that all of an order arrives in stock at the same time and can be used immediately.
8. Each stock item is independent and money cannot be saved by substituting other items or grouping several items into a single order.

(Waters, 1992: 33)

The EOQ provides a useful mathematically-derived approximation of an order quantity which can be used as a guideline for inventory management decisions (Waters, 1992: 34). The model can be modified to relax many of the EOQ assumptions, achieving an order quantity that more closely reflects the probabilistic demand patterns prevalent in many business environments. It is considered to be “robust” in that it computes an optimal order quantity that can be deviated from (within reason) with little impact on the total relevant costs incurred (Silver & Peterson, 1985: 180). The graph in Figure 3-1 shows the relationship between carrying and ordering costs at the EOQ quantity (Q).

The point where carrying costs equal ordering costs represents the EOQ order quantity which minimizes total costs.

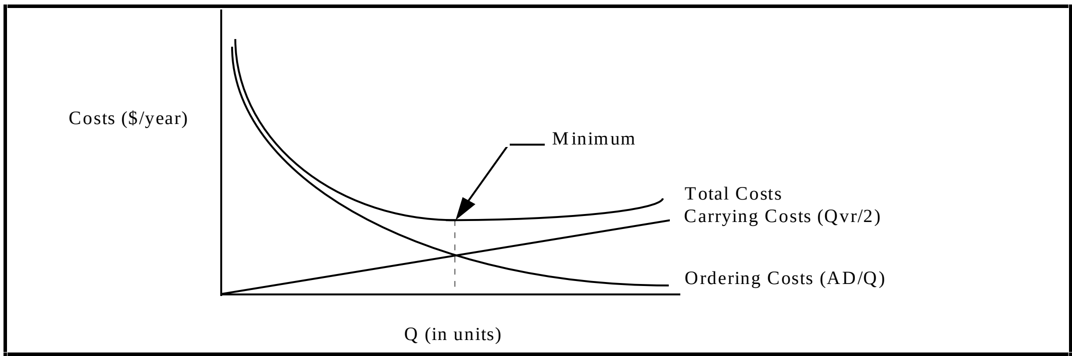

Figure 3-1. Cost Functions of the EOQ

(Silver & Peterson, 1985: 178)

In a 1986 survey of inventory management practices employed by United States business firms, 84% of the respondents indicated that they used the EOQ model to some extent. The same survey revealed, however, that 74% of the companies reported that they did not consider the demand for their products as constant and 30% indicated that their ordering costs were not fixed or constant (Osteryoung, McCarty & Reinhart, 1986: 42-43). Since constant demand and ordering costs are explicit assumptions of the EOQ model, application of the EOQ model under these conditions seems paradoxical.

Fulbright provides an explanation of the popularity of the EOQ model, even when the EOQ assumptions are not satisfied. By surveying numerous articles pertaining to the use of the EOQ model, Fulbright compiled a list of the distinct advantages and disadvantages of this inventory management technique (1979: 8). The advantages provide some insight into the persistent use of the EOQ even under circumstances that justify the use of a more efficient and economical inventory method. Fulbright's list of EOQ advantages and disadvantages, culled from relevant inventory literature, are presented as follows:

Advantages of the EOQ

1. Ease of calculation. The EOQ and the associated total cost can be calculated in two steps. If changes in input parameters occur, the EOQ can be easily recomputed to reflect the new changes (Kaimann, 1969: 68-69).
2. When demand for an item is variable, the EOQ calculates a reorder quantity with associated total costs that do not differ dramatically from the Wagner-Whitin dynamic programming algorithm (Kaimann, 1969: 68-69).

Disadvantages of the EOQ

1. Not well suited for items with variable demand. The business world is characterized by uncertainty and the assumption of constant demand for an item is seldom met. As a result, the EOQ should only be used in situations were "the demand and usage conditions are as assumed" (Kaimann, 1969: 68-69).
2. The EOQ understates total cost for goods with variable demand. The Wagner-Whitin algorithm was found to estimate total costs more accurately for goods with non-continuous demand (Philippakis, 1970: 66).
3. It is difficult to accurately estimate the EOQ input parameters. Relevant EOQ costs are based on estimates and these costs are not readily available from most accounting systems (Dopuch, Birnberg, & Demski, 1974: 268).

Of the three disadvantages of the EOQ, the greatest drawback is the inability of the EOQ model to precisely compute reorder quantities for items with variable or non-continuous demand (Fulbright, 1979: 9).

DLA's EOQ Model

DLA uses a modified version of the classic EOQ to manage its inventories. The primary difference is DLA's use of Quarterly Forecasted Demand (QFD) in lieu of annual demand (D). For most items, the QFD is calculated by using a composite forecasting method. This method employs a combination of three of nine available individual forecasting techniques. The nine techniques are listed in Table 3-2.

Table 3-2. DLA Forecasting Methods

Technique #	Forecasting Method
1	Exponential Smoothing, non-program related
2	Exponential Smoothing, program related
3	Double Exponential Smoothing, non-program related
4	Double Exponential Smoothing, program related
5	Moving Average, non-program related
6	Moving Average, program related
7	Non Parametric, non-program related
8	Non Parametric, program related
9	Damped trend, non-program related

(Bilikam, 1996: Interview and notes)

For items that experience declining demand due to the phase-out of the related weapon system or end item, DLA uses the program related exponential smoothing method. For other items, DLA employs a composite of the program related moving average, exponential smoothing, and double exponential smoothing forecasting techniques to arrive at the item's final QFD. The final QFD is used as a variable in DLA's EOQ model which follows:

$$EOQ_{DLA} = \sqrt{\frac{2(4QFD)A}{vr}}$$

Where:

A = Fixed cost component incurred with each replenishment ($)
QFD = Quarterly Forecasted Demand rate of the item (in units/unit time)
v = Unit variable cost of the item ($/unit)
r = Carrying charge ($/$/unit time)

To decrease computation time, DLA utilizes a “T” factor (T) to factor out the constants in the EOQ equation. The constants are the ordering costs (A), the holding costs (r), and the constant term “2” included in the model. DLA sets (T) equal to these constants as follows:

$$T = 2\sqrt{\frac{2A}{r}}$$

Where:

T = Constant factor for the EOQ_{DLA} model
A = Fixed cost component incurred with each replenishment ($)
r = Carrying charge ($/$/unit time)

The final EOQ_{DLA} model is presented below:

$$EOQ_{DLA} = T\sqrt{\frac{QFD}{v}} = \frac{T}{2v}\sqrt{4(QFD)v}$$

Where:

T = Constant factor for the EOQ_{DLA} model
QFD = Quarterly Forecasted Demand rate of the item (in units/unit time)
v = Unit variable cost of the item ($/unit)

(Bilikam, 1996: Interview and notes)

Periodic Order Quantity

The periodic order quantity (POQ) is an alternative approach to the economic order quantity where the EOQ is expressed as a time supply of the average item demand. Specifically, the EOQ is divided by the average demand to arrive at an integer period time supply.

$$T_{EOQ} = \frac{EOQ}{\overline{D}} = \sqrt{\frac{2A}{\overline{D}vr}}$$

Where:

A = Fixed cost component incurred with each replenishment ($)
$\overline{D}$ = The average demand rate out to the horizon (N periods)
v = Unit variable cost of the item ($/unit)
r = Carrying charge ($/$/unit time)

Any replenishment of an item is made large enough to cover exactly the requirements of the calculated integer number of periods. The major advantage of the POQ is its potential to obtain lower total variable cost when there is significant variability in the demand pattern (Silver & Peterson, 1985: 242).

Silver-Meal Heuristic

Developed in 1973 by Edward Silver and Harlan Meal, the Silver-Meal heuristic selects order sizes for items with known, deterministic demand that varies over time (1973: 64). The heuristic, as a simple variation of the basic EOQ model, uses the same criteria as the EOQ to determine the replenishment quantity: the reduction of total order and carrying costs to the lowest possible level when selecting the timing and size of replenishments (Silver, 1979: 71).

Replenishment quantities are ordered at the beginning of every period and each replenishment will last for *T* periods. The cumulative demands that occurred during the *T* periods are combined to determine the order replenishment quantity or order size

(Tersine, 1982: 344-345). As such, the Silver-Meal criterion function, when a replenishment arrives at the beginning of the first period and satisfies requirements to the end of the *T*th period, is presented below:

$$\frac{\text{(Setup cost)} + \text{(Total carrying costs to end of period } T\text{)}}{T}$$

(Silver & Peterson, 1985: 233)

Determining each replenishment quantity over the known demand horizon is an iterative process. The Silver-Meal heuristic evaluates the total relevant costs per unit time, TRCUT(*T*), for successive *T* periods. Total relevant costs consist of *A*, the fixed cost component incurred with each replenishment, and *r*, the inventory carrying charge. The replenishment quantity for *T* time periods is determined when total relevant costs begin to increase or:

$$\text{TRCUT}(T + 1) > \text{TRCUT}(T)$$

(Silver & Peterson, 1985: 234).

In Chapter II, the variability coefficient (VC) was presented to categorize demand patterns. When an item's VC is less than 0.2, signifying that demand for the item is constant and continuous, Silver and Peterson recommend the use of the EOQ model to determine replenishment quantities. However, when demand for an item is "lumpy" with a VC greater than 0.2, they recommend the use of the Silver-Meal heuristic (Silver & Peterson, 1985: 238).

Advantages of the Silver-Meal Heuristic

1. More useful than the basic EOQ when there is variability in the demand rate.
2. Simpler to use than dynamic programming applications, such as the Wagner-Whitin algorithm.

3. Does not crucially depend on the number of forecasted demand periods.
4. Tends to use demand data of only the first few periods, recognizing that the deterministic demand assumption becomes less reasonable as one projects further into the future.

Disadvantages of the Silver-Meal Heuristic

1. More computationally involved than the basic EOQ.
2. Ineffective when the demand pattern drops rapidly with time over several periods.
3. Also ineffective when there are a large number of periods having no demand.

(Silver & Peterson, 1985: 236-239)

Conclusion

An overview of the EOQ, POQ, and the Silver-Meal heuristic, three frequently cited continuous review inventory models, was provided. The basic arithmetic equations of the models were presented followed by an examination of the demand conditions that favor the use of each model. Furthermore, the advantages and disadvantages of the models were listed and discussed. This chapter provided the background necessary to understand the methodology for the proposed simulation experiments involving the DLA EOQ requirements model, the Periodic Order Quantity model, and Silver-Meal heuristic, as discussed in the next chapter.

IV. Methodology

Introduction

This chapter will explain the methodology chosen to answer the investigative questions posed in Chapter I. The methods outlined in this chapter will guide the researchers throughout the research process. First, the scientific method will be explored, followed by a discussion of why simulation will be used in this study's experimental design. Next, the simulation models, simulation language, and relevant variables to be monitored in the simulation runs will be introduced. Verification and validation of the simulation models will be discussed followed by a presentation of the starting conditions and steady state determination of each model. Statistical procedures to determine the number of output data runs required for conclusive results will be summarized. Finally, a description of the paired difference test of hypothesis to analyze the simulation output data will be presented.

The Scientific Method

Research is the formal, systematic application of the scientific method to the study of problems. The goal of research is to explain, predict, and/or control phenomena occurring in an experimental setting (Gay & Diehl, 1992: 6). The main distinguishing characteristics of scientific research, according to Sekaran are presented in Table 4-1:

Table 4-1. Characteristics of Scientific Research

Characteristic	Definition
Purposiveness	The researcher begins with a definite purpose for the research
Rigor	The study has a theoretical base and methodological design
Testability	The research lends itself to testing logically developed hypotheses
Replicability	The results of the tests of hypotheses should be supported when the study is repeated in similar circumstances
Precision	How close the findings, based on a sample, are to "reality"
Confidence	The probability that our estimations are correct - confidence level
Objectivity	The conclusions of data analysis are based on the facts resulting from the actual data and not on subjective or emotional values
Generalizability	The scope of applicability of research findings
Parsimony	Simplicity in explaining the phenomena or problems that occur

(Sekaran, 1992: 10-14)

Steps of the Scientific Method

The scientific method is an orderly process entailing five sequential steps as listed in Table 4-2:

Table 4-2. Five Steps of the Scientific Method

Step #	Description
1	Selection and definition of the problem.
2	Formulation of hypotheses
3	Collection of data
4	Analysis of data
5	Statement of conclusions regarding confirmation or disconfirmation of the hypotheses

(Gay & Diehl, 1992: 6)

The importance of sequentially following the steps of the scientific method cannot be overstated. It is the strict adherence to these steps that separates formal research from other investigative techniques. The application of the scientific method to problem solving lends credence to final research findings by ensuring problems are

carefully identified, data is systematically gathered and analyzed, and conclusions are drawn in an objective manner.

Selection and Definition of the Problem

As presented in Chapter I, this study will focus on DSCC's item classification scheme and their blanket application of the DLA EOQ inventory requirements model. In particular, the problem statement for this research is:

> **Do different dynamic lot sizing models, when applied to the existing DSCC classification structure, provide lower total variable costs and inventory levels than the DLA EOQ requirements model?**

To help answer the above problem statement, two investigative questions were formulated:

1. What are the results, in terms of costs and inventory levels, of applying the DLA EOQ requirements model, the Silver-Meal Heuristic, and the Periodic Order Quantity model to low, medium, and high demand items?

This question will quantify the costs of DSCC's use of the EOQ requirements model to determine stock levels for low, medium, and high demand items. DLA's EOQ model attempts to minimize total inventory costs by balancing ordering and holding costs. The total inventory costs and stock levels incurred by DLA as a result of their use of the EOQ model will be measured to compare against the total inventory costs and stock levels DLA may experience by the implementation of a dynamic lot-sizing model such as the Silver-Meal heuristic or the Periodic Order Quantity technique.

2. Which inventory model, the DLA EOQ requirements model, the Silver-Meal Heuristic, or the Periodic Order Quantity model is more effective in minimizing inventory costs and levels for low, medium, and high demand items?

This question will determine the most appropriate inventory requirements model for the tested low, medium, and high demand items. The minimization of inventory costs and levels will serve as the criterion for determining whether the DLA requirements model, the Silver-Meal heuristic, or the Periodic Order Quantity is the most effective inventory model for different SMCC classes. In addition, this question will investigate whether DSCC will benefit by applying other dynamic lot-sizing models to different inventory demand classifications instead of their present EOQ requirements model.

Experimentation

The research design chosen to answer the investigative questions in this study is experimentation. "Experimentation is a special type of investigation used to determine *whether* and *in what manner* variables are related to each other" (Emory, 1980: 330). The experimental method tests hypotheses concerning cause-effect relationships (Gay & Diehl, 1992: 382). Furthermore, this method concerns itself with determining whether there is a relation between an independent variable (IV) and a dependent variable (DV). This relationship is observed by manipulating the IV and detecting the presence or absence of the DV (Emory, 1980: 331).

Experimental Design

Computer simulation is the method selected as the research technique for use in this study. Simulation provides the opportunity to evaluate alternative ways of attaining goals without excessive risk, cost, or time use which would be required if proposed

solutions were tried out on real situations before implementation. In addition, it "is a very pragmatic and flexible technique for evaluating alternative choices in situations where formal analytic models are inappropriate, incompatible, or incomplete in relation to the system being studied" (House, 1977: 1-2).

Why Simulation?

Standard inventory and probabilistic models that are amenable to mathematical analysis restrict the user to small scale systems and require simplifying assumptions that are unrealistic for the study of a large inventory system (Wagner, 1970: 498). In addition, an analytical solution to inventory problems is often impossible to obtain when problems involve risk or uncertainty. "A mathematical model using the analytic approach can become incredibly complex because of numerous interacting variables. Simulation offers an alternative for complex problems not suitable for rigorous analytical analysis" (Tersine, 1982: 401).

Classical analytical inventory models, such as the EOQ, are primarily developed based on deterministic demand and lead-time assumptions. In rare instances, these deterministic assumptions are reasonable. In most situations, however, inventory requirements are not known for certain and require probability distributions to describe anticipated demand. The inclusion of stochastic demand increases the complexity of modeling. In many cases, when deterministic assumptions cannot be made about both demand and lead-time, mathematical or analytical solutions become prohibitive (Ahadiat, 1986: 29-30). Simulation is a technique frequently used to overcome the limiting assumptions of analytical models.

According to Nasrollah Ahadiat, the three major advantages of using simulation for solving inventory problems are:

1. In many cases simulation is the only possible method for analyzing a complex inventory system.
2. Simulation provides the ability to trace the past or future behavior of a complex system through finely divided time intervals.
3. Using simulation, alternative inventory policies can be explored.

(Ahadiat, 1986: 32)

Simulation Language

Experimentation of the DLA EOQ requirements model, the Silver-Meal heuristic, and the Periodic Order Quantity model will be conducted on Digital Equipment Corporation's (DEC) VAX 6420 mainframe computer using the Pritsker Corporation's SLAM II program (version 4.1). The FORTRAN subroutines to be used in conjunction with the SLAM II computer models will be compiled and linked using the DEC VAX FORTRAN Compiler (Version 6.1).

Simulation Models

Three inventory simulation models will be created, building on Berry and Tatge's 1995 thesis results. While Berry and Tatge depended on the DLA forecasting method to provide projected demand for their models, this study will incorporate a variation of the NF1 (Naïve Forecast 1) into the models to accomplish the same task. The models will gather demand frequency and quantity data for a full quarter. The data will then be used to compute appropriate order quantities for the three months of next quarter using the three ordering schemes. This demand data will then be used to actually place the demands in the next quarter. This will allow for comparisons of results across models without the bias of the DLA's smoothed forecast obscuring the analysis of the models' performance. Each of the three inventory simulation models will be run with low,

medium, and high demand input data to obtain the output data required to answer the investigative questions and address the problem statement.

Relevant Variables

The relevant variables in this study are total variable cost and average on-hand inventory. Total variable cost indicates the amount of capital invested in inventory, representing both ordering and holding costs. It is essential for inventory managers to reduce excessive total variable costs in light of today's declining DoD budget. Closely related to total variable cost is average on-hand inventory. Average on-hand inventory directly contributes to the amount of total variable costs incurred. The greater the amount of inventory carried from period to period generally results in higher total variable costs during the same time-frame.

This research experiment will simulate the DLA EOQ requirements model, the Silver-Meal heuristic, and the Periodic Order Quantity model to obtain output data to address the investigative questions and, ultimately, the problem statement. Before collecting data for analysis, each of the computer simulation models must be verified and validated to ensure they are working as designed.

Verification and Validation

The computer code for the separate functions of each simulation model will be systematically examined to verify that the models are working properly. In addition, the SLAM II syntax check and the DEC VAX FORTRAN compiler will be relied upon to aid in verifying the program and FORTRAN code. Finally, instead of using an input distribution for the frequency of orders and the number of units ordered, the researchers will substitute each SMCC's mean value for these distributions, calculated from the input data provided by DSCC. Each model will then be run and the output compared with an

analytic computation of the expected result. A match of the computer simulation results with the analytic computations will verify the models are working properly.

Input Data

To determine the input distributions and starting conditions for the three models, stratified random national stock number (NSN) samples from SMCCs 1, 5, and 0 will be collected by DSCC personnel. These samples will be representative of the demand patterns of DSCC's low, medium, and high demand items. The data collected for each item will include the national stock number (NSN), the past sixteen quarters of demand data, the unit price, SMCC, lead-time, and nomenclature. This data will be analyzed to determine the input distributions and starting conditions for each SMCC.

Input theoretical distributions for the frequency of orders and the number of units ordered will be calculated using a statistical analysis software package. These theoretical distributions will be evaluated using the chi-square goodness of fit test. If the chi-square analysis indicates that theoretical distributions do not closely approximate the data, then empirical distributions will be generated in the form of arrays for input to the models.

Additionally, the data provided by DSCC will be analyzed to determine the starting conditions for the models. Values for unit price, lead time, reorder point (DLA EOQ requirements model only), and on-hand inventory will be calculated and inserted into each computer simulation model.

Steady State

According to Hoover and Perry, steady state is achieved when the probability distribution of the state variable is no longer changing over time. It is at this time "the state variable has reached steady state, or more correctly, reached its steady-state distribution" (Hoover & Perry, 1990: 309). To achieve steady state, the computer

simulation model must be run for a certain time period so that the output is not affected by the starting conditions. The time that elapses from the beginning of the simulation run to the beginning of steady state is known as the transient period. Data that accumulates during the transient period must be eliminated to ensure the final output reflects the true steady state of the system. It is always assumed that simulation output is generated from models that are running under steady state conditions. As such, the transient period for computer simulation models must be determined so that observations that occur during the transient period can be eliminated (Law & Kelton, 1991: 545).

Law and Kelton have suggested using a moving average on a measured variable to determine the end of the transient period or the beginning of steady state. They have observed that steady state begins when the moving average curve for the measured variable begins to level off (Law & Kelton, 1991: 545-551). For this experiment, steady state will be determined by running each model and applying a moving average to measure total variable costs and average inventory. Five 200 year runs of each model will be processed with the relevant variables collected annually. Moving averages will be acquired from the output and analyzed to determine the length of the transient period. Output data collection for each model will begin when the models enter into steady state.

Number of Output Data Collection Runs

According to R. Kleijnen, "If the number of simulation runs (sample size n_i) is small relative to the noise of the simulated systems (variance σ_i^2), then we obtain inconclusive results" (1987: 46). To guard against this possibility, statistical procedures are used to determine the number of runs that must be conducted in a simulation experiment. In this study, the output generated for each relevant variable from the different simulation models represents a distinct population. As such, the sample size to

estimate (μ_1 - μ_2) to within a 100(1-α)% confidence interval will be determined by the following formula:

$$n = \left(\frac{t_{n-1}^{\alpha/2}}{(.2) * (\bar{x}_d)} \right)^2 s^2_{\bar{x}_d}$$

Where:

n = Sample size
t_{n-1} = t-statistic
$\bar{x}_d$ = Difference of means between simulation runs
$s^2_{\bar{x}_d}$ = Variance of simulation runs
α = Desired 100(1-α)% confidence interval

In this study, the data required for insertion into the above formula will be generated by conducting five steady state pilot runs of the simulation models for each type of demand. The appropriate number of runs required to achieve a 95% confidence interval will then be calculated.

Inferences About the Difference Between Two Population Means

Output data from the simulation runs will be analyzed using the paired difference test of hypothesis. The paired difference test is used in situations where the assumption of independent samples is invalid. In this study, independence is violated because the quantity of average on-hand inventory directly influences the amount of total variable costs. In other words, larger inventory levels result in greater total variable costs and vice versa.

The paired difference test uses the difference between sample observations to make inferences about mean μ_D. Mean μ_D is equal to the difference (μ_1 - μ_2): i.e., the mean of the population (sample) of differences equals the difference between the population (sample) means. “In many cases a paired difference experiment can provide

more information about the difference between population means than an independent samples experiment. The differencing removes variability due to the dimension on which observations are paired" (McClave & Benson, 1994: 423). The hypothesis-testing based on the paired difference experiment is summarized below:

$$\mathbf{H_o}: (\mu_1 - \mu_2) = D_O \text{ or } \mu_D = 0$$

$$\mathbf{H_a}: (\mu_1 - \mu_2) \neq D_O \text{ or } \mu_D \neq 0$$

Test statistic: $t = \dfrac{\bar{x} - D_O}{s_D / \sqrt{n_D}}$

Rejection region: $t < -t_{\alpha/2}$ or $t > t_{\alpha/2}$ where $t_{\alpha/2}$ has $(n_D - 1)$ df.

(McClave & Benson, 1994: 424).

One assumption that must be met to employ the paired difference test of hypothesis is the requirement that the differences be randomly selected from the population of differences. This assumption will be met in this study through the use of random number seeds in the simulation runs.

Statement of Hypotheses Conclusions

The results of the paired difference test of hypothesis will be presented. These results will provide the data to answer the investigative questions and the problem statement. After the investigative questions and problem statement have been addressed, conclusions from this research and recommendations for future research will be presented.

Summary

This chapter has explained the methodology that will be used to investigate the investigative questions posed in Chapter I. Characteristics of the scientific method were

summarized followed by a discussion of why simulation will be used in this study's experimental design. Then, the simulation models, language, and relevant variables to be used in the simulation runs were introduced. Verification and validation of the simulation models was discussed followed by a presentation of the starting conditions and steady state determination of each model. Statistical procedures to determine the number of output data runs required for conclusive results were summarized. Finally, a description of the paired difference test of hypothesis to analyze the simulation output data was presented. The next chapter will explain the actual experimentation process and results of this research.

V. Data Analysis

Introduction

This chapter addresses the analysis of input data, validation and verification of the computer simulation models, the generation of output data from the models, and the statistical techniques used to analyze both the input and output data. First, the steps used to acquire and analyze the input data will be presented, along with the statistical methods used for analysis. Next will be a discussion of the specific steps used to validate and verify the computer simulation models. Finally, the techniques used to generate and analyze the output data, including the statistical tests applied to results, will be described.

Analysis of Input Data

200 random stratified sample NSNs for each of the three SMCCs were retrieved by Mr. James Wagner, Operations Analyst at DSCC. According to Mr. Wagner, the samples are representative of the demand patterns experienced by items in each SMCC. Relevant data fields retrieved for each NSN, along with sample data elements, are provided in Appendix A. Each SMCC file was analyzed individually to acquire mean input starting conditions and appropriate demand data for input into the simulation models. During the initial analysis, it was discovered that there were a number of NSNs which were included in the SMCC groupings which did not exhibit the appropriate characteristics (number of annual demands and/or annual demand dollar value) for inclusion in that particular SMCC (see Table 1-6 for SMCC characteristics). Cathy Fisher from the Stock Control Directorate at DSCC indicated that the items may have "jumped SMCCs" in the past, and that attempting to average 16 quarters of historical data would factor-in older demands for some items which represented previous period

declining or increasing trends in the demand history. Since these items did not exhibit characteristics of the SMCC to which they were now assigned (because of the inclusion of older data) they were eliminated from consideration. Table 5-1 presents the number of NSNs which remained in each SMCC after eliminating the atypical items.

Table 5-1. Adjusted NSN Count

SMCC	NSNs
1	180
5	127
0	154

Next, an attempt was made to acquire theoretical distributions for each SMCC for both the mean time-between-orders and mean quantity-per-demand. Mean time-between-orders in days for each NSN in a SMCC was calculated as follows:

$$\textbf{NSN Mean TBO(in days)} = \frac{91}{\sum_{i=1}^{16} \mathrm{RDF}_i / 16}$$

Where:

TBO = Time Between Orders
RDF_i = Quarterly Recurring Demand Frequency

Mean quantity-per-demand for each NSN in a SMCC was calculated as follows:

$$\textbf{NSN Mean QPD (in units)} = \frac{\sum_{i=1}^{16} \mathrm{RDF}_i}{\sum_{i=1}^{16} \mathrm{RDQ}_i}$$

Where:

QPD = Quantity Per Demand
RDF_i = Quarterly Recurring Demand Frequency
RDQ_i = Quarterly Recurring Demand Quantity

Three files containing the mean TBOs for SMCCs 1, 5, and 0 were analyzed to fit a theoretical distribution to each data set. Theoretical distributions would enable the

computer simulation models to be run with an appropriate TBO and QPD input distribution based on realistic data. However, chi-square goodness of fit tests revealed that theoretical distributions were inappropriate for any of the TBO or QPD data sets. Appendix B provides a sample chi-square analysis output. The individual chi-square theoretical distribution analyses of TBO and QPD data are shown in Tables 5-2 and 5-3.

Table 5-2. Mean TBO Theoretical Distribution Evaluation by SMCC

SMCC	Primary Distribution	Evaluation
0	Exponential	Not recommended - use empirical distribution
1	Uniform	Not recommended - use empirical distribution
5	Uniform	Not recommended - use empirical distribution

Table 5-3. Mean QPD Theoretical Distribution Evaluation by SMCC

SMCC	Primary Distribution	Evaluation
0	Exponential	Not recommended - use empirical distribution
1	Weibull (E)	Not recommended - use empirical distribution
5	Weibull (K)	Use distribution with caution

An empirical distribution is used when theoretical distributions are inappropriate or unavailable. Empirical distributions were used to represent the demand frequencies and quantities in this research because the chi-square goodness of fit test found theoretical distributions to be unsatisfactory. Appendix C contains a sample empirical distribution proposed by a statistical software package for SMCC 0, along with the appropriate SLAM code to construct the arrays required by the models.

Model Starting Conditions

Starting values for each SMCC's unit price, lead-time, on-hand inventory, and reorder point (for the DLA EOQ model) are represented in Appendix D and were calculated as follows:

1. Unit price - computed using the straight mean acquired from the data set.

2. Lead time - calculated by adding the administrative and production lead times for each NSN and averaging these figures.
3. On-hand inventory - one year's average demand for a SMCC was used as a starting inventory.
4. The starting reorder point quantity for the DLA EOQ model was calculated by multiplying the average daily demand rate times the lead time as is represented by the following formula:

$$\textbf{Reorder Point (ROP)} = \frac{\sum_{i=1}^{4} \text{ARDQ}_i / 4}{365} \text{ x LT}$$

Where:

ARDQ_i = Annual Recurring Demand Quantity

Model Validation and Verification

To verify the models replicated the processes of the DLA EOQ requirements model, the Silver-Meal heuristic, and the Periodic Order Quantity model, mean values for each SMCC's TBO and QPD were inserted into the respective create nodes for the computer simulation models. For each SMCC, the performance of the computer models was verified by running the models for one year and collecting appropriate variables at the end of each quarter (see Appendices O through Q). This output was compared to results that were calculated analytically and model verification was completed when computer output based on the mean input agreed with first-year analytical results.

Number of Output Data Collection Runs

As discussed in Chapter IV, statistical procedures are necessary to determine the number of runs that must be conducted in a simulation experiment to achieve a specified

level of confidence. In this study, the output data from five pilot runs was used to calculate the number of runs required to obtain a 95% confidence interval. The pilot run output data and the calculations to determine the number of runs required to achieve a 95% confidence level are presented in Tables 5-4 through 5-9. Based on the largest calculated value from tables below, the researchers in this study conducted 86 simulation runs for each model.

Table 5-4. Simulation Runs Test - SMCC 0 Average On-Hand Inventory

	POQ	S-M			POQ	EOQ			EOQ	S-M	
Pilot Run	$\overline{X}_1$	$\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$	**Pilot Run**	$\overline{X}_1$	$\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$	**Pilot Run**	$\overline{X}_1$	$\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$
1	10.2	5.4	-4.9	**1**	10.2	0.0	-10.2	**1**	0.0	5.4	5.4
2	7.1	3.9	-3.2	**2**	7.1	0.0	-7.1	**2**	0.0	3.9	3.9
3	13.5	9.5	-4.0	**3**	13.5	0.0	-13.5	**3**	0.0	9.5	9.5
4	8.1	3.0	-5.1	**4**	8.1	0.0	-8.1	**4**	0.0	3.0	3.0
5	11.7	6.8	-4.9	**5**	11.7	0.0	-11.7	**5**	0.0	6.8	6.8
$\overline{X}_d$			-4.4	$\overline{X}_d$			-10.1	$\overline{X}_d$			5.7
$s^2_{\overline{X}_d}$			0.6	$s^2_{\overline{X}_d}$			6.7	$s^2_{\overline{X}_d}$			6.6
C			-0.9	**C**			-2.0	**C**			1.1
t_{n-1}			2.776	t_{n-1}			2.776	t_{n-1}			2.776
# Runs			6.1	**# Runs**			12.7	**# Runs**			39.0

Table 5-5. Simulation Runs Test - SMCC 1 Average On-Hand Inventory

Pilot Run	POQ $\overline{X}_1$	S-M $\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$	Pilot Run	POQ $\overline{X}_1$	EOQ $\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$	Pilot Run	EOQ $\overline{X}_1$	S-M $\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$
1	1103.0	1076.0	-27.0	1	1103.0	81.2	-1021.8	1	81.2	1076.0	994.8
2	1148.0	1113.0	-35.0	2	1148.0	81.4	-1066.6	2	81.4	1113.0	1031.6
3	1173.0	1158.0	-15.0	3	1173.0	35.5	-1137.5	3	35.5	1158.0	1122.5
4	1093.0	1082.0	-11.0	4	1093.0	99.5	-993.5	4	99.5	1082.0	982.5
5	1189.0	1182.0	-7.0	5	1189.0	30.5	-1158.5	5	30.5	1182.0	1151.5
$\overline{X}_d$			-19.0	$\overline{X}_d$			-1075.6	$\overline{X}_d$			1056.6
$s^2_{\overline{X}_d}$			136	$s^2_{\overline{X}_d}$			5105.1	$s^2_{\overline{X}_d}$			5821.3
C			-3.8	C			-215.1	C			211.3
t_{n-1}			2.776	t_{n-1}			2.776	t_{n-1}			2.776
# Runs			72.6	# Runs			0.9	# Runs			1.0

Table 5-6. Simulation Runs Test - SMCC 5 Average On-Hand Inventory

Pilot Run	POQ $\overline{X}_1$	S-M $\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$	Pilot Run	POQ $\overline{X}_1$	EOQ $\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$	Pilot Run	EOQ $\overline{X}_1$	S-M $\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$
1	1.8	3.2	1.4	1	1.8	19.7	17.0	1	19.7	3.2	-16.5
2	9.1	12.6	3.5	2	9.1	22.7	13.6	2	22.7	12.6	-10.1
3	3.0	6.3	3.3	3	3.0	13.8	10.7	3	13.8	6.3	-7.4
4	4.0	5.4	1.4	4	4.0	7.0	3.0	4	7.0	5.4	-1.6
5	5.2	7.7	2.5	5	5.2	25.5	20.3	5	25.5	7.7	-17.8
$\overline{X}_d$			2.4	$\overline{X}_d$			13.1	$\overline{X}_d$			-10.7
$s^2_{\overline{X}_d}$			1.0	$s^2_{\overline{X}_d}$			45.7	$s^2_{\overline{X}_d}$			44.4
C			0.5	C			2.6	C			-2.1
t_{n-1}			2.776	t_{n-1}			2.776	t_{n-1}			2.776
# Runs			32.9	# Runs			51.1	# Runs			74.6

Table 5-7. Simulation Runs Test - SMCC 0 Total Variable Cost

Pilot Run	POQ $\overline{X}_1$	S-M $\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$	Pilot Run	POQ $\overline{X}_1$	EOQ $\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$	Pilot Run	EOQ $\overline{X}_1$	S-M $\overline{X}_2$	$\overline{X}_2 - \overline{X}_1$
1	164.5	87.1	-77.4	1	164.5	10.6	-153.9	1	10.6	87.1	76.5
2	119.0	67.9	-51.1	2	119.0	11.9	-107.1	2	11.9	67.9	56.0
3	209.9	145.5	-64.4	3	209.9	10.9	-199.0	3	10.9	145.5	134.6
4	133.7	54.7	-79.0	4	133.7	8.4	-125.3	4	8.4	54.7	46.3
5	181.3	110.3	-71.0	5	181.3	10.6	-170.7	5	10.6	110.3	99.7
$\overline{X}_d$			-68.6	$\overline{X}_d$			-151.2	$\overline{X}_d$			82.6
$s^2_{\overline{X}_d}$			128.6	$s^2_{\overline{X}_d}$			1322.4	$s^2_{\overline{X}_d}$			1265.1
C			-13.7	C			-30.2	C			16.5
t_{n-1}			2.776	t_{n-1}			2.776	t_{n-1}			2.776

# Runs			5.3	# Runs			11.1	# Runs			35.7

Table 5-8. Simulation Runs Test - SMCC 1 Total Variable Cost

	POQ	S-M			POQ	EOQ			EOQ	S-M	
Pilot Run	$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_2 - \bar{X}_1$	Pilot Run	$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_2 - \bar{X}_1$	Pilot Run	$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_2 - \bar{X}_1$
1	6569.0	6431.0	-138.0	1	6569.0	750.0	-5819.0	1	750.0	6431.0	5681.0
2	6835.0	6598.0	-237.0	2	6835.0	747.8	-6087.2	2	747.8	6598.0	5850.2
3	6985.0	6895.0	-90.0	3	6985.0	471.7	-6513.3	3	471.7	6895.0	6423.3
4	6548.0	6481.0	-67.0	4	6548.0	858.1	-5689.9	4	858.1	6481.0	5622.9
5	7015.0	6972.0	-43.0	5	7015.0	442.7	-6572.3	5	442.7	6972.0	6529.3
$\bar{X}_d$			-115.0	$\bar{X}_d$			-6136.3	$\bar{X}_d$			6021.3
$s^2_{\bar{X}_d}$			5881.5	$s^2_{\bar{X}_d}$			158647.0	$s^2_{\bar{X}_d}$			180867.5
C			-23.0	C			-1227.3	C			1204.3
t_{n-1}			2.776	t_{n-1}			2.776	t_{n-1}			2.776
# Runs			85.7	# Runs			0.8	# Runs			1.0

Table 5-9. Simulation Runs Test - SMCC 5 Total Variable Cost

	POQ	S-M			POQ	EOQ			EOQ	S-M	
Pilot Run	$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_2 - \bar{X}_1$	Pilot Run	$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_2 - \bar{X}_1$	Pilot Run	$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_2 - \bar{X}_1$
1	314.2	513.4	199.2	1	314.2	2771.0	2456.8	1	2771.0	513.4	-2257.6
2	1332.0	1828.0	496.0	2	1332.0	3204.0	1872.0	2	3204.0	1828.0	-1376.0
3	487.4	970.3	482.9	3	487.4	2003.0	1515.6	3	2003.0	970.3	-1032.7
4	611.5	812.3	200.8	4	611.5	1161.2	549.5	4	1161.0	812.3	-348.7
5	769.9	114.0	344.1	5	769.9	3468.0	2698.1	5	3468.0	1114.0	-2354.0
$\bar{X}_d$			344.6	$\bar{X}_d$			1818.4	$\bar{X}_d$			-1473.8
$s^2_{\bar{X}_d}$			20967.2	$s^2_{\bar{X}_d}$			721523.7	$s^2_{\bar{X}_d}$			714769.6
C			68.9	C			363.7	C			-294.8
t_{n-1}			2.776	t_{n-1}			2.776	t_{n-1}			2.776
# Runs			34.0	# Runs			42.0	# Runs			63.4

Analysis of Output Data

This study will use the paired difference test of hypotheses to test the difference between sample observations of both average on-hand inventory and total variable cost for each SMCC to make inferences about mean μ_D. The paired difference test results for average on-hand inventory and TVC are presented below:

Average On-Hand Inventory

Average on-hand inventory represents the mean stockage level of items that would be maintained at DLA for each inventory method and each type of demand. The output results for this variable are summarized in Table 5-11 below:

Table 5-11. Average On-Hand Inventory Levels

Model	Type of Demand	Mean	St. Dev.
DLA EOQ - SMCC 0	Low	0.00	0.00
Silver-Meal - SMCC 0	Low	6.74	2.49
POQ SMCC 0	Low	8.44	5.44
DLA EOQ - SMCC 5	Medium	12.88	7.30
Silver-Meal - SMCC 5	Medium	6.89	5.50
POQ SMCC 5	Medium	5.16	4.50
DLA EOQ - SMCC 1	High	62.64	23.27
Silver-Meal - SMCC 1	High	1131.91	43.34
POQ SMCC 1	High	1131.63	39.81

1. Average on-hand inventory comparison of the DLA EOQ Requirements Model-SMCC 0 and Silver-Meal Heuristic-SMCC 0.

Table 5-12. SMCC 0 DLA EOQ and Silver-Meal Paired Difference Test

	DLA EOQ Inv SMCC 0	Silver-Meal Inv SMCC 0
Mean	0.00	6.74
Standard Deviation	0.00	2.49
$\overline{X}_D$ **(Silver Meal - EOQ)**		6.74
t		25.07
t$\alpha/2$		1.97

H_O: Silver-Meal - DLA EOQ = 0
H_a: Silver-Meal - DLA EOQ $\neq$ 0

The calculated t value of 25.07 greatly exceeds the critical t value of 1.97, indicating strong evidence that the mean on-hand inventory for the Silver-Meal model is greater than that of the DLA EOQ model for low demand items.

2. Average on-hand inventory comparison of the DLA EOQ Requirements Model-SMCC 0 and Periodic Order Quantity Model-SMCC 0.

Table 5-13. SMCC 0 DLA EOQ and POQ Paired Difference Test

	DLA EOQ Inv SMCC 0	POQ Inv SMCC 0
Mean	0.00	8.44
Standard Deviation	0.00	5.44
$\overline{X}_D$ **(POQ - EOQ)**		8.44
t		14.38
t$\alpha/2$		1.97

H_O: POQ - DLA EOQ = 0
H_a: POQ - DLA EOQ $\neq$ 0

The calculated t value of 14.38 greatly exceeds the critical t value of 1.97, indicating strong evidence that the mean on-hand inventory for the POQ model is greater than that of the DLA EOQ model for low demand items.

3. Average on-hand inventory comparison of the Silver-Meal Heuristic-SMCC 0 and Periodic Order Quantity Model-SMCC 0.

Table 5-14. SMCC 0 Silver-Meal and POQ Paired Difference Test

	Silver-Meal Inv SMCC 0	POQ Inv SMCC 0
Mean	6.74	8.44
Standard Deviation	2.49	5.44
$\overline{X}_D$ **(POQ - Silver Meal)**		1.70
t		3.09
t$\alpha/2$		1.97

H_O: POQ - Silver Meal = 0
H_a: POQ - Silver Meal ≠ 0

The calculated t value of 3.09 exceeds the critical t value of 1.97, indicating that the mean on-hand inventory for the POQ model is greater than that of the Silver-Meal model for low demand items.

4. Average on-hand inventory comparison of the DLA EOQ Requirements Model-SMCC 1 and Silver-Meal Heuristic-SMCC 1.

Table 5-15. SMCC 1 DLA EOQ and Silver-Meal Paired Difference Test

	DLA EOQ Inv SMCC 1	Silver-Meal Inv SMCC 1
Mean	62.64	1131.91
Standard Deviation	23.27	43.34
$\overline{X}_D$ **(Silver Meal - EOQ)**		1069.26
t		188.54
t$\alpha/2$		1.97

H_O: Silver Meal - EOQ = 0
H_a: Silver Meal - EOQ $\neq$ 0

The calculated t value of 188.54 is significantly higher than the critical t value of 1.97, indicating that the mean on-hand inventory for the Silver-Meal model is greater than that of DLA's EOQ model for high demand items.

5. Average on-hand inventory comparison of the DLA EOQ Requirements Model-SMCC 1 and Periodic Order Quantity Model-SMCC 1.

Table 5-16. SMCC 1 DLA EOQ and POQ Paired Difference Test

	DLA EOQ Inv SMCC 1	POQ Inv SMCC 1
Mean	62.64	1131.63
Standard Deviation	23.27	39.81
$\overline{X}_D$ **(POQ - EOQ)**		1068.98
t		199.63
t$\alpha/2$		1.97

H_O: POQ - EOQ = 0
H_a: POQ - EOQ $\neq$ 0

The calculated t value of 199.63 is significantly higher than the critical t value of 1.97, indicating that the mean on-hand inventory for the POQ model is greater than that of DLA's EOQ model for high demand items.

6. Average on-hand inventory comparison of the Silver-Meal Heuristic-SMCC 1 and Periodic Order Quantity Model-SMCC 1.

Table 5-17. SMCC 1 Silver-Meal and POQ Paired Difference Test

	Silver-Meal Inv SMCC 1	POQ Inv SMCC 1
Mean	1131.91	1131.63
Standard Deviation	43.34	39.81
$\overline{X}_D$ **(Silver Meal - POQ)**		0.28
t		0.14
t$\alpha/2$		1.97

H_O: Silver Meal - POQ = 0
H_a: Silver Meal - POQ $\neq$ 0

The calculated t value of .14 is less than the critical t value of 1.97, indicating that there is insufficient evidence to reject the null hypothesis that the mean on-hand inventory for the POQ and the Silver-Models differ appreciably for high demand items.

7. Average on-hand inventory comparison of the DLA EOQ Requirements Model-SMCC 5 and Silver-Meal Heuristic-SMCC 5.

Table 5-18. SMCC 5 DLA EOQ and Silver-Meal Paired Difference Test

	DLA EOQ Inv SMCC 5	Silver-Meal Inv SMCC 5
Mean	12.88	6.89
Standard Deviation	7.30	5.50
$\overline{X}_D$ **(EOQ - Silver Meal)**		5.99
t		5.96
t$\alpha/2$		1.97

H_O: EOQ - Silver Meal = 0
H_a: EOQ - Silver Meal $\neq$ 0

The calculated t value of 5.96 exceeds the critical t value of 1.97, indicating that the mean on-hand inventory for the EOQ model is greater than that of the Silver-Meal model for medium demand items.

8. Average on-hand inventory comparison of the DLA EOQ Requirements Model-SMCC 5 and Periodic Order Quantity Model-SMCC 5.

Table 5-19. SMCC 5 DLA EOQ and POQ Paired Difference Test

	DLA EOQ Inv SMCC 5	POQ Inv SMCC 5
Mean	12.88	5.16
Standard Deviation	7.30	4.50
$\overline{X}_D$ **(EOQ - POQ)**		7.72
t		8.26
t$\alpha/2$		1.97

H_O: EOQ - POQ = 0
H_a: EOQ - POQ $\neq$ 0

The calculated t value of 8.26 exceeds the critical t value of 1.97, indicating that the mean on-hand inventory for the EOQ model is greater than that of the POQ model for medium demand items.

9. Average on-hand inventory comparison of the Silver-Meal Heuristic-SMCC 5 and Periodic Order Quantity Model - SMCC 5.

Table 5-20. SMCC 5 Silver-Meal and POQ Paired Difference Test

	Silver-Meal Inv SMCC 5	POQ Inv SMCC 5
Mean	6.89	5.16
Standard Deviation	5.50	4.50
$\overline{X}_D$ **(Silver Meal - POQ)**		1.73
t		6.71
t$\alpha/2$		1.97

H_O: Silver Meal - POQ $= 0$
H_a: Silver Meal - POQ $\neq 0$

The calculated t value of 6.71 exceeds the critical t value of 1.97, indicating that the mean on-hand inventory for the Silver-Meal model is greater than that of the POQ model.

Total Variable Costs

Total variable costs represent DLA's expenses to order and hold inventory. The output results for this variable are summarized in Table 5-21 below:

Table 5-21. Total Variable Cost Values

Model	Type of Demand	Mean	St. Dev.
DLA EOQ - SMCC 0	**Low**	10.48	2.90
Silver-Meal - SMCC 0	**Low**	106.59	34.98
POQ - SMCC 0	**Low**	135.83	76.37
DLA EOQ - SMCC 5	**Medium**	1919.77	928.57
Silver-Meal - SMCC 5	**Medium**	1026.81	763.3
POQ - SMCC 5	**Medium**	786.54	626.76
DLA EOQ - SMCC 1	**High**	630.44	133.84
Silver-Meal - SMCC 1	**High**	6731.38	251.46
POQ - SMCC 1	**High**	6733.43	231.94

1. Total variable cost comparison of the DLA EOQ Requirements Model-SMCC 0 and Silver-Meal Heuristic-SMCC 0.

Table 5-22. SMCC 0 DLA EOQ and Silver-Meal Paired Difference Test

	DLA EOQ TVC SMCC 0	Silver-Meal TVC SMCC 0
Mean	10.48	106.59
Standard Deviation	2.90	34.98
$\overline{X}_D$ **(EOQ - Silver Meal)**		96.11
t		25.38
t$\alpha/2$		1.97

H_O: EOQ - Silver Meal = 0
H_a: EOQ - Silver Meal $\neq$ 0

The calculated t value of 25.38 greatly exceeds the critical t value of 1.97, indicating that the mean total variable costs for the Silver-Meal model are much greater than that of the EOQ model for low demand items.

2. Total variable cost comparison of the DLA EOQ Requirements Model-SMCC 0 and Periodic Order Quantity Model-SMCC 0.

Table 5-23. SMCC 0 DLA EOQ and POQ Paired Difference Test

	DLA EOQ TVC SMCC 0	POQ TVC SMCC 0
Mean	10.48	135.83
Standard Deviation	2.90	76.37
$\overline{X}_D$ **(EOQ - POQ)**		125.35
t		15.19
t$\alpha/2$		1.97

H_O: EOQ - POQ = 0
H_a: EOQ - POQ ≠ 0

The calculated t value of 15.19 exceeds the critical t value of 1.97, indicating that the mean total variable costs for the POQ model are greater than that of the EOQ for low demand items as evidenced by the $\overline{X}_D$ value of $125.35.

3. Total variable cost comparison of the Silver-Meal Heuristic-SMCC 0 and Periodic Order Quantity Model-SMCC 0.

Table 5-24. SMCC 0 Silver-Meal and POQ Paired Difference Test

	Silver-Meal TVC SMCC 0	POQ TVC SMCC 0
Mean	106.59	135.83
Standard Deviation	34.98	76.37
$\overline{X}_D$ **(POQ - Silver Meal)**		29.24
t		3.77
t$\alpha/2$		1.97

H_O: POQ - Silver Meal = 0
H_a: POQ - Silver Meal ≠ 0

The calculated t value of 3.27 exceeds the critical t value of 1.97, indicating that the mean total variable costs for the POQ model is greater than that of the Silver-Meal model for low demand items as evidenced by the $\overline{X}_D$ value of $29.24.

4. Total variable cost comparison of the DLA EOQ Requirements Model-SMCC 1 and Silver-Meal Heuristic-SMCC 1.

Table 5-25. SMCC 1 DLA EOQ and Silver-Meal Paired Difference Test

	DLA EOQ TVC SMCC 1	Silver-Meal TVC SMCC 1
Mean	630.44	6731.38
Standard Deviation	133.84	251.46
$\overline{X}_D$ **(Silver Meal - EOQ)**		6100.94
t		184.99
tα/2		1.97

H_O: Silver Meal - EOQ = 0
H_a: Silver Meal - EOQ $\neq$ 0

The calculated t value of 184.99 greatly exceeds the critical t value of 1.97, indicating that the mean total variable costs for the Silver-Meal model are greater than that of the EOQ for high demand items.

5. Total variable cost comparison of the DLA EOQ Requirements Model-SMCC 1 and Periodic Order Quantity Model-SMCC 1.

Table 5-26. SMCC 1 DLA EOQ and POQ Paired Difference Test

	DLA EOQ TVC SMCC 1	POQ TVC SMCC 1
Mean	630.44	6733.43
Standard Deviation	133.84	231.94
$\overline{X}_D$ **(POQ - EOQ)**		6102.99
t		195.71
t$\alpha/2$		1.97

H_O: POQ - EOQ = 0
H_a: POQ - EOQ $\neq$ 0

The calculated t value of 195.71 greatly exceeds the critical t value of 1.97, indicating that the mean total variable costs for the POQ model are greater than that of the EOQ for high demand items.

6. Total variable cost comparison of the Silver-Meal Heuristic-SMCC 1 and Periodic Order Quantity Model-SMCC 1.

Table 5-27. SMCC 1 Silver-Meal and POQ Paired Difference Test

	Silver-Meal TVC SMCC 1	POQ TVC SMCC 1
Mean	6731.38	6733.43
Standard Deviation	251.46	231.94
$\overline{X}_D$ **(POQ - Silver Meal)**		2.05
t		0.18
t$\alpha/2$		1.97

H_O: POQ - Silver Meal = 0
H_a: POQ - Silver Meal $\neq$ 0

The calculated t value of 0.18 is less than the critical t value of 1.97, indicating that there is insufficient evidence to reject the null hypothesis that the mean total variable cost for the POQ and the Silver-Meal models differ appreciably for high demand items.

7. Total variable cost comparison of the DLA EOQ Requirements Model-SMCC 5 and Silver-Meal Heuristic-SMCC 5.

Table 5-28. SMCC 5 DLA EOQ and Silver-Meal Paired Difference Test

	DLA EOQ TVC SMCC 5	Silver-Meal TVC SMCC 5
Mean	1919.77	1026.81
Standard Deviation	928.57	763.3
$\overline{X}_D$ **(EOQ - Silver Meal)**		892.96
t		6.74
t$\alpha/2$		1.97

H_O: EOQ - Silver Meal = 0
H_a: EOQ - Silver Meal ≠ 0

The calculated t value of 6.74 exceeds the critical t value of 1.97, indicating that the mean total variable costs for the EOQ model are greater than that of the Silver-Meal for medium demand items.

8. Total variable cost comparison of the DLA EOQ Requirements Model-SMCC 5 and Periodic Order Quantity Model-SMCC 5.

Table 5-29. SMCC 5 DLA EOQ and POQ Paired Difference Test

	DLA EOQ TVC SMCC 5	POQ TVC SMCC 5
Mean	1919.77	786.54
Standard Deviation	928.57	626.76
$\overline{X}_D$ **(EOQ - POQ)**		1133.23
t		9.28
t$\alpha/2$		1.97

H_O: EOQ - POQ = 0
H_a: EOQ - POQ ≠ 0

The calculated t value of 9.28 exceeds the critical t value of 1.97, indicating that the mean total variable costs for the EOQ model are greater than that of the POQ for medium demand items.

9. Total variable cost comparison of the Silver-Meal Heuristic-SMCC 5 and Periodic Order Quantity Model-SMCC 5.

Table 5-30. SMCC 5 Silver-Meal and POQ Paired Difference Test

	Silver-Meal TVC SMCC 5	POQ TVC SMCC 5
Mean	1026.81	786.54
Standard Deviation	763.30	626.76
$\overline{X}_D$ **(Silver Meal - POQ)**		240.27
t		6.70
t$\alpha/2$		1.97

H_O: Silver Meal - POQ = 0
H_a: Silver Meal - POQ ≠ 0

The calculated t value of 6.70 exceeds the critical t value of 1.97, indicating that the mean total variable costs for the Silver-Meal model are greater than that of the POQ for medium demand items.

Summary

In this chapter, the methods used to analyze the data obtained from DSCC to arrive at model starting conditions were presented. The verification and validation process was documented. In addition, the statistical tests performed on the output data to

test the research hypotheses were detailed. Chapter VI provides conclusions drawn from this research, as well as recommendations for future research.

VI. Conclusions, Implications and Recommendations

Introduction

This chapter will answer the investigative questions that were postulated in Chapter I. The information that is obtained from answering these questions will serve to address the problem statement. Finally, research conclusions and recommendations for future research are provided.

Problem Statement and Investigative Questions

The Chapter I problem statement and investigative questions have served to focus the research methodology and experimental design implemented in this study. The procedures used by the researchers were designed to gather data in an attempt to specifically answer the investigative questions and address the problem statement. Each of the investigative questions will be answered below using the data generated from the simulation experiments. Then the research question will be addressed with the information obtained from the investigative questions:

Investigative Questions

1. What are the results, in terms of costs and inventory levels, of applying the DLA EOQ requirements model, the Silver-Meal Heuristic, and the Periodic Order Quantity model to low, medium, and high demand items?

A summary of the results obtained from the data analysis in Chapter V is provided in the following tables:

Table 6-1. Summary of Average On-Hand Inventory Results

Demand Type	**DLA EOQ**	**POQ**	**Silver-Meal**
Low	0.00	8.44	6.74
Medium	12.88	5.16	6.89
High	62.64	1131.63	1131.91

Table 6-2. Summary of Total Variable Cost Results

Demand Type	**DLA EOQ**	**POQ**	**Silver-Meal**
Low	10.48	135.83	106.59
Medium	1919.77	786.54	1026.81
High	630.44	6733.43	6731.43

As the results above indicate, a direct relationship exists between the two relevant variables, average on-hand inventory and total variable cost. The greater the amount of inventory that DSCC carries from one period to the next causes an increase in their inventory holding costs. It is clear that different demand conditions produce different results from the inventory models analyzed in this study.

The second investigative question will be anwered using the results of the statistical analyses performed on the low, medium, and high demand categories of items managed by DSCC.

2. Which inventory model, the DLA EOQ requirements model, the Silver-Meal Heuristic, or the Periodic Order Quantity model is more effective in minimizing inventory costs and levels for low, medium, and high demand items?

Low demand (SMCC 0) - Tables 6-1 and 6-2 indicate that the DLA EOQ model clearly outperformed the POQ and Silver-Meal models in terms of TVC and average on-

hand inventory under low demand conditions. Statistical analysis of this demand category revealed that the EOQ performed best, followed by the Silver-Meal heuristic and the Periodic Order Quantity. It should be noted, however, that the DLA requirements model never carried on-hand inventory. The original model verification and validation process did not disclose any errors that would contribute to this outcome. An additional thorough check of the DLA EOQ requirements model computer code did not detect a cause. The extremely irregular demand patterns which the model encountered during the simulation of low demand items rendered the EOQ model incapable of maintaining a sufficient inventory balance. Because the EOQ used a quarterly forecasted value to provide an appropriate order quantity, a significant spike in demand in subsequent quarters would render the EOQ order quantity artificially low, resulting in an insufficient quantity of items ordered to satisfy demands. Additionally, the EOQ attempts to balance ordering and holding costs, but because of erratic and limited demand, low ordering costs, and no backorder penalties, the model does not maintain inventory in this low demand situation. As was discussed in Chapter II, the EOQ model is subject to demand pattern and lead-time assumptions. Specifically, for the EOQ to achieve optimal performance, demand should be constant and continuous and lead time minimized. While numerically superior in terms of minimizing on-hand inventory and total variable costs, the EOQ model's inability to maintain an inventory of low demand items could seriously degrade customer service for low demand items.

Medium demand (SMCC 5) - Statistical analysis judged the Periodic Order Quantity as the superior model for medium demand items. This model provided the

lowest total variable cost and average on-hand inventory results, followed by the Silver-Meal heuristic and the DLA EOQ model. As discussed in Chapter III, the POQ has the potential to perform best in terms of lower total variable cost when there is variability in the demand pattern. Medium demand provided the POQ with the opportunity to achieve enhanced performance.

High demand (SMCC 1) - The DLA EOQ requirements model was clearly superior in comparisons against the POQ and the Silver-Meal models. The differences between the DLA EOQ and the other two models in terms of average on-hand inventory and total variable cost was statistically significant, approaching an order of magnitude of ten. Analysis of the high demand output data interestingly revealed no statistical difference between the performance of the POQ and Silver-Meal models.

Further investigation into the performance contrast between the EOQ and the two other models indicated that the starting conditions of the simulation experiment may have contributed to the extreme differences. The DLA EOQ model employs a reorder point to trigger orders when on-hand and pipeline (inbound) inventory falls to a certain level. This reorder point is allowed to vary depending on the daily demand rate and the replenishment lead-time. The purpose of the reorder point is to maintain a stock of inventory to satisfy demands received during replenishment lead-time. As a result, the EOQ effectively maintains minimal, yet sufficient on-hand inventory for high demand items.

In contrast, neither the Periodic Order Quantity nor Silver-Meal model have a reorder-point mechanism to signal when to place an order. All three models begin their simulation runs with identical starting inventory levels to satisfy demands received during the transient phase, providing for consistent comparisons across models as discussed in Chapter IV. The EOQ must fall to a certain level before a replenishment

order is placed. However, since the POQ and Silver-Meal lack a reorder point mechanism, the on-hand inventory balance is not considered when the models place orders, making the two models extremely sensitive to the starting on-hand inventory balance for high demand items.

Problem Statement

> **Do different dynamic lot sizing models, when applied to the existing DSCC classification structure, provide lower total variable costs and inventory levels than the DLA EOQ requirements model?**

This study found evidence to indicate that different dynamic lot-sizing models can provide lower total variable cost and on-hand inventory levels than the DLA EOQ requirements model. The Periodic Order Quantity was the statistically superior model for medium demand items. In addition, the Silver-Meal heuristic ranked second in all three categories of demand. The DLA requirements model ranked first in both the low and high demand categories. However, issues concerning customer service and model starting conditions indicate the need for further research in these areas.

Recommendations for Future Research

This study identified several potential areas for future research as follows:

1. Evaluate DLA's blanket use of QFD to forecast for all items regardless of SMCC classification. Many forecasting models exist that may provide better results as judged by the mean absolute deviation (MAD) accuracy measure.

2. Simulate the DLA EOQ requirements model from a customer service perspective. Customer service measures of effectiveness can include the number of backorders in the system and the amount of time an average backorder waits before being

filled. The simulation model should incorporate a monetary fine whenever backorders occur and a daily penalty for the amount of time the backorder remains unfilled. In this experiment, backorders were not penalized. Although the DLA EOQ requirements model was statistically superior in the low demand, it is unclear whether this superior performance was achieved at the expense of customer service.

Summary

This chapter answered the investigative questions proposed originally in Chapter I. These answers were used to address this study's problem statement. The Periodic Order Quantity model provided lower inventory levels and total variable costs than the DLA EOQ and the Silver-Meal models for the medium demand category. The DLA EOQ requirements model was found to provide lower inventory levels and total variable costs than the either the POQ or the Silver-Meal models in the low and high demand categories. Finally, recommendations for future research were developed.

Appendix A. Sample of Data from DSCC

NSN	NOUN	UNIT PRICE	SMCC	WSIC1	WSIC2	ALT	PLT	QFD	QFD NEW	ROP QTY
2510010241054	FENDER,VEH	$338.5 8	1	Z	1	24	153	45	0	155
2510013175493	GRILLE,META	$55.2 8	1	F	3	68	112	115	23	245

ARDQ 96/2	ARDF 96/2	RDQ 96/2	RDQ 96/1	RDQ 95/4	RDQ 95/3	RDF 96/2	RDF 96/1	RDF 95/4	RDF 95/3
201	154	37	17	58	89	35	13	41	65
390	306	125	96	73	96	83	74	69	80

ARDQ 95/2	ARDF 95/2	RDQ 95/2	RDQ 95/1	RDQ 94/4	RDQ 94/3	RDF 95/2	RDF 95/1	RDF 94/4	RDF 94/3
217	187	35	31	77	74	33	27	67	60
281	243	83	76	80	42	74	67	62	40

ARDQ 94/2	ARDF 94/2	RDQ 94/2	RDQ 94/1	RDQ 93/4	RDQ 93/3	RDF 94/2	RDF 94/1	RDF 93/4	RDF 93/3
347	260	57	73	107	110	43	54	86	77
148	131	63	54	22	9	54	48	22	7

ARDQ 93/2	ARDF 93/2	RDQ 93/2	RDQ 93/1	RDQ 92/4	RDQ 92/3	RDF 93/2	RDF 93/1	RDF 92/4	RDF 92/3
390	341	90	76	130	94	71	70	117	83
65	40	0	8	34	23	0	8	17	15

Acronym Glossary

NSN - National Stock Number
SMCC - Selective Management Category Code
WSIC1 - Weapon System Identification Code 1
WSIC2 - Weapon System Identification Code 2
ALT - Administrative Lead Time
PLT - Production Lead Time
QFD - Quarterly Forecasted Demand
QFD NEW - New Quarterly Forecasted Demand
ROP QTY - Reorder Point Quantity
ARDQ - Annual Recurring Demand Quantity
RDQ - Recurring Demand Quantity
RDF - Recurring Demand Frequency

Summary of Sample: Data From MQPDSMC0.DAT

Sample Characteristic	Value
Observation Type	Real Valued
Number of Observations	154
Minimum Observation	1.00000E-05
Maximum Observation	87.8333
Mean	7.28608
Median	3.45000
Variance	110.994
Skewness	3.99975

Guided Selection Model Rankings For Sample: Data From MQPDSMC0.DAT
Range of Random Variable

During the fitting process UniFit considers distributions having any reasonable range (not just the specified range), provided they produce values in the specified range at least 99% of the time.

Specified random variable range   Between 0. and 87.8333

Relative Evaluation of Candidate Models

Models	Relative Score (0-100)	Random Variable Range (if different from specified)
1-Exponential	75.0	At least 0.
2-Gamma	75.0	At least 0.
3-Weibull	75.0	At least 0.
4-Uniform	18.8	
5-Inverse Gaussian	6.3	At least 0.

Current Primary Model

1-Exponential

Absolute Evaluation of the Primary Model

Based on a heuristic evaluation, we do not recommend using the primary model. If you are doing simulation, then you should use an empirical distribution rather than the primary model (unless you can show that it is good).

Appendix C. Sample Proposed Empirical Arrays

Empirical DF Representation of Sample: Data From MQPDSMC0.DAT
SLAMSYSTEM Representation:

```
Model Usage   <temp> = DRAND(<stream>)
              GGTBLN(<i>,<j>,<temp>)
              where <temp> is a temporary real variable
```

Control Statements

```
ARRAY(<i>,11)/.0000,.7922,.8961,.9545,.9805,.9870,.9935,
.9935,.9935,.9935,1.0000;

ARRAY(<j>,11)/1,8.78334,17.5667,26.35,35.1333,
43.9167,52.7,61.4833,70.2666,79.05,87.8333;
```

Appendix D. Starting Conditions for Each SMCC

SMCC	Annual Demand Frequency	MTBO	MQPD	XX(1) Annual Demand	XX(15) Unit Price	XX(6) Total Lead-Time	XX(3) ROPQ
1	259	1.41	12.88	3315	$ 58.58	190	1726
5	7.2	51.05	6.32	45.5	$1,408.61	300	38
0	1.21	299.80	7.29	8.82	$ 141.30	190	5

Acronym Glossary

SMCC - Selective Management Category Code
MTBO - Mean Time Between Orders
MQPD - Mean Quantity Per Demand
ROPQ - Reorder Point Quantity

Appendix E. Input Arrays

The following input arrays were inserted into the SMCC 0, 1, and 5 simulation models to generate the time between orders (TBO) and the mean quantity per demand (QPD).

SMCC 0

```
ARRAY(1,11)/.0000,.3117,.7468,.7987,.8961,.9610,.9611,.9612,
      .9613,.9614,1.0000;
ARRAY(2,11)/1.0,145.6,291.2,436.8,582.4,728.,873.6,
      1019.2,1164.8,1310.4,1456.;
ARRAY(3,11)/.0000,.7922,.8961,.9545,.9805,.9870,.9935,.9936,
      .9937,.9938,1.0000;
ARRAY(4,11)/1.0,8.78334,17.5667,26.35,35.1333,
      43.9167,52.7,61.4833,70.2666,79.05,87.8333;
```

SMCC 1

```
ARRAY(1,11)/.0000,.0889,.2167,.3778,.5111,.6556,.7500,.8556,
      .9611,.9944,1.0000;
ARRAY(2,11)/.07731,.40352,.72973,1.05594,1.38215,1.70836,
      2.03456,2.36077,2.68698,3.01319,3.3394;
ARRAY(3,11)/.0000,.8667,.9222,.9444,.9500,.9778,.9833,.9834,
      .9835,.9944,1.0000;
ARRAY(4,11)/1.22611,19.6255,38.025,56.4244,74.8239,93.2233,
      111.623,130.022,148.422,166.821,185.221;
```

SMCC 5

```
ARRAY(1,11)/.0000,.2047,.3543,.5433,.6614,.7480,.8110,.8661,
      .9449,.9606,1.0000;
ARRAY(2,11)/19.158,28.4422,37.7264,47.0106,56.2948,65.579,
      74.8632,84.1474,93.4316,102.716,112.;
ARRAY(3,11)/.0000,.9055,.9528,.9764,.9843,.9844,.9921,.9922,
      .9923,.9924,1.0000;
ARRAY(4,11)/1.00001,13.8643,26.7286,39.5929,52.4572,65.3215,
              78.1857,91.05,103.914,116.779,129.643;
```

Appendix F. DLA EOQ SLAM Model Variable Definitions

Variable	Definition
XX(1)	On-hand Inventory
XX(3)	Reorder point quantity
XX(4)	Backorders awaiting stock replenishment
XX(5)	Quarterly demand
XX(6)	Lead time to receipt of stock replenishment
XX(7)	Calculated EOQ from USERF(2)
XX(8)	Daily demand rate
XX(9)	Pipeline inventory
XX(10)	Cumulative annual demand
XX(11)	Day of the year (1-365)
XX(14)	Quarterly forecast demand
XX(15)	Unit Price
XX(21)	Annual orders placed counter
XX(22)	Daily carrying cost
XX(23)	Cumulative daily on-hand inventory
XX(24)	Annual total variable cost
XX(25)	Daily inventory carrying rate
XX(26)	Cumulative daily number of backorders
XX(33)	Average daily inventory (used in VAR statement)
XX(35)	Annual ordering cost (component of TVC)
XX(36)	Cumulative annual carrying cost (component of TVC)
XX(60)	Time-between orders array variable (from percentage array)
XX(61)	Time between orders array variable (value from array)
XX(62)	Quantity-per-demand array variable (from percentage array)
XX(63)	Quantity-per-demand array variable (value from array)
XX(99)	Dummy variable used to round and truncate QPD value

Appendix G. Silver-Meal SLAM Model Variable Definitions

Variable	Definition
XX(1)	On-hand Inventory
XX(4)	Backorders awaiting replenishment
XX(5)	Quarterly demand
XX(6)	Lead time to receipt of stock replenishment
XX(14)	Quarterly forecast demand
XX(15)	Unit Price
XX(21)	Annual orders placed counter
XX(22)	Daily carrying cost
XX(23)	Cumulative daily on-hand inventory
XX(24)	Annual total variable cost
XX(25)	Part of daily inventory carrying cost
XX(26)	Month One Order Quantity
XX(27)	Month Two Order Quantity
XX(28)	Month Three Order Quantity
XX(31)	Unit Price multiplied by the Monthly Holding Cost
XX(33)	Average daily inventory (used in VAR statement)
XX(35)	Annual ordering cost (component of TVC)
XX(36)	Cumulative annual carrying cost (component of TVC)
XX(51)	Total Relevant Cost (TRC) (Ordering and Holding) for One Month Order
XX(52)	Total Relevant Cost (TRC) for Two Month Order
XX(53)	Total Relevant Cost (TRC) for Three Month Order
XX(60)	Time-between orders array variable (from percentage array)
XX(61)	Time between orders array variable (value from array)
XX(62)	Quantity-per-demand array variable (value from array)
XX(63)	Quantity-per-demand array variable (value from array)
XX(99)	Dummy variable used to round and truncate QPD value

Appendix H. Periodic Order Quantity SLAM Model Variable Definitions

Variable	Definition
XX(1)	On-hand Inventory
XX(4)	Backorders awaiting replenishment
XX(5)	Quarterly demand
XX(6)	Lead time to receipt of stock replenishment
XX(14)	Quarterly forecast demand
XX(15)	Unit Price
XX(21)	Annual orders placed counter
XX(22)	Daily carrying cost
XX(23)	Cumulative daily on-hand inventory
XX(24)	Annual total variable cost
XX(25)	Part of daily inventory carrying cost
XX(26)	Month One Order Quantity
XX(27)	Month Two Order Quantity
XX(28)	Month Three Order Quantity
XX(33)	Average daily inventory (used in VAR statement)
XX(35)	Annual ordering cost (component of TVC)
XX(36)	Cumulative annual carrying cost (component of TVC)
XX(60)	Time-between orders array variable (from percentage array)
XX(61)	Time between orders array variable (value from array)
XX(62)	Quantity-per-demand array variable (value from array)
XX(63)	Quantity-per-demand array variable (value from array)
XX(70)	Monthly Order Quantity
XX(71)	Calculated value from Periodic Order Quantity formula
XX(99)	Dummy variable used to round and truncate QPD value

Appendix I. DLA EOQ SLAM Model

Comments are provided (*in italics and under applicable lines of code*) for each section of the model as to its purpose and function.

I. Control Statement

```
GEN,GOULET&ROLLMAN,EOQ0,9/1/1996,5,N,N,Y/Y,N,Y/1,132;
```

Model authors, title, date, number of runs (1).

```
LIMITS,1,5,100000;
```

Limits statement; number of files, attribute number used, file space required.

```
ARRAY(1,11)/.0000,.3117,.7468,.7987,.8961,.9610,.9611,.9612,.9613,.9614,
      1.0000;
ARRAY(2,11)/1.0,145.6,291.2,436.8,582.4,728.,873.6,1019.2,
      1164.8,1310.4,1456.;
```

Input arrays; time between orders.

```
ARRAY(3,11)/.0000,.7922,.8961,.9545,.9805,.9870,.9935,.9936,.9937,.9938,
      1.0000;
ARRAY(4,11)/1.0,8.78334,17.5667,26.35,35.1333,43.9167,52.7,
      61.4833,70.2666,79.05,87.8333;
```

Input arrays; quantity per demand.

```
SEEDS,53060595(1),49626694(2);
```

Seeds statements for independent starting conditions.

```
INITIALIZE,,72800,Y;
```

Initialize statement; run for 100 years

```
;MONITOR,CLEAR,73000;
;MONITOR,SUMRY,73365,365,Y;
```

Monitor clear and summary statements.

```
INTLC,XX(15)=142,XX(6)=190,XX(1)=15;
```

Starting conditions; EOQ, unit price, lead time, reorder point, on-hand inventory.

```
RECORD,TNOW,TIME,,T,364,,,Y;
```

Record statement; recorded variable, label, table output, interval (days).

```
;VAR,XX(14),Q,QFD;
;VAR,XX(5),D,ACTUAL;
VAR,XX(33),O,AVGINV;
;VAR,XX(4),B,BACKORD;
```

```
VAR,XX(24),C,TVC
```

Variable statements; Variable of interest, plot label, output label.

```
TIMST,XX(1),XX1 OH INV;
TIMST,XX(2),XX2 START EOQ;
TIMST,XX(3),XX3 ROP;
TIMST,XX(4),XX4 AVG BO;
TIMST,XX(5),XX5 QRTLY DMD;
TIMST,XX(7),XX7 USERF2 EOQ;
TIMST,XX(8),XX8 DDR;
TIMST,XX(9),XX9PPLN INV;
TIMST,XX(10),XX10CUM DEMAND;
TIMST,XX(11),XX11CUM DAYS;
TIMST,XX(14),XX14QFD;
TIMST,XX(21),XX21ORDERS PLACED;
TIMST,XX(22),XX22DAIL CAR CST;
TIMST,XX(36),XX36CUM CAR COST
```

Initiation of measurement for time persistent variables (measured every day).

```
NETWORK;
```

Network statement; Calls SLAM network.

II. Demand Generation and Issue/Backorder Process

```
DMND  CREATE;
      ACTIVITY;
      ASSIGN,XX(60)=DRAND(5),XX(61)=GGTBLN(1,2,XX(60));
      ACTIVITY,XX(61),,DMND;
      ACTIVITY,,,QTY;
```

Demand creation; One entity created, calls empirical arrays for time between order, entity runs assigned time, reenters create node to begin process again. Cloned entity from assign node sent to QTY assign node for calculation of quantity per demand.

```
QTY   ASSIGN,XX(62)=DRAND(5),XX(63)=GGTBLN(3,4,XX(62)),XX(99)=XX(63)+0.5,
      II=XX(99),ATRIB(5)=II,2;
```

Quantity per demand assignment; entity assigned quantity from second set of empirical arrays, number truncated, quantity assigned to attribute.

```
      ACTIVITY,,,MLR;
      ACTIVITY,91,,DDR;
```

Send one clone to update quarterly forecasted demand. The other entity goes one quarter into the future to provide same demand pattern and quantity.

```
MLR   UNBATCH,5,1;
      ACTIVITY;
```

Unbatch node; Reads quantity assigned to attribute, generates corresponding number of entities representing number of items in order.

```
ASSIGN,XX(14)=XX(14)+1;
      ACTIVITY,,,END;
```

Update quarterly forecasted demand variable with order quantity, provides to EOQ formula in subroutine. Entity terminates.

```
DDR   UNBATCH,5,1;
      ACTIVITY;
QTR   ASSIGN,XX(5)=XX(5)+1,XX(10)=XX(10)+1,1;
```

Increment quarterly and cumulative demand by number of entities in order.

```
      ACTIVITY,,XX(1).GT.0,INV;
```

If there sufficient inventory to fill requisition from shelf, go to the issue inventory node.

```
      ACTIVITY,,,BACK;
```

If not, go to the back order node.

```
INV   ASSIGN,XX(1)=XX(1)-1,1;
```

Issue and decrement on hand inventory counter.

```
      ACTIVITY;
END   TERMINATE;
```

Entity dies.

```
BACK  ASSIGN,XX(4)=XX(4)+1,1;
```

Increment number of backorders.

```
      ACTIVITY,,,END;
```

Entity dies.

III. Replenishment Cyc1e: Daily releveling, order placement, order receipt, daily adjustment of variables.

```
REPL  CREATE,1,,1,,1;
      ACTIVITY;
```

Create one entity every day to check inventory levels and adjust values of specific variables.

```
ZAAB  ASSIGN,XX(25)=.1/364,XX(22)=XX(1)*XX(15)*XX(25),
      XX(36)=XX(36)+XX(22),XX(11)=XX(11)+1,XX(26)=XX(26)+XX(4),
      XX(23)=XX(23)+XX(1),1;
```

Compute daily inventory carrying cost, increment: cumulative annual carrying cost, day of the current year, cumulative number of backorders, cumulative daily on-hand inventory.

```
      ACTIVITY;
      GOON,1;
      ACTIVITY,,XX(7).EQ.0,END;
      ACTIVITY,,XX(1)+XX(9).LE.XX(3);
```

Go to CUM node if on-hand and pipeline inventory less than reorder point quantity.

```
      ACTIVITY,,,INFO;
```

If not, go to INFO node to collect daily on-hand inventory statistics.

```
CUM   ASSIGN,XX(21)=XX(21)+1,1;
```

Increment annual orders placed counter.

```
      ACTIVITY;
EOQ   ASSIGN,ATRIB(2)=XX(7),XX(9)=XX(9)+ATRIB(2),1;
```

Place order by setting entities second attribute equal to the most recently calculated EOQ quantity, increment pipeline quantity by same.

```
      ACTIVITY,XX(6);
```

Entities wait lead time for order arrival.

```
PREI  COLCT,XX(1),PRE REPLIN INV;
```

Collect pre-inventory replenishment statistics on on-hand inventory.

```
      ACTIVITY;
PREB  COLCT,XX(4),PRE REPLEN BO;
```

Collect pre-inventory replenishment statistics on backorders.

```
      ACTIVITY,,,PLDEC;
```

Go to pipeline decrement node to record shipment receipt.

```
      ACTIVITY;
INFO  COLCT,XX(1),AVG INV;
```

Collect statistics on on-hand inventory.

```
      ACTIVITY,,,END;
```

Entity dies.

```
PLDEC ASSIGN,XX(9)=XX(9)-ATRIB(2),1;
```

Decrement pipeline inventory by received shipment quantity.

```
      ACTIVITY,,ATRIB(2).GE.XX(4),MORE;
```

If quantity received is greater than backorder quantity, go to MORE node.

```
      ACTIVITY,,,LESS;
```

If quantity received is less than backorder quantity, go to LESS node.

```
MORE  ASSIGN,XX(1)=XX(1)+ATRIB(2)-XX(4),XX(4)=0,1;
```

Increment on-hand inventory by shipment received quantity then decrement by backorder quantity if quantity in the shipment was more than the quantity of backorders.

```
      ACTIVITY,,,END;
```

Entity dies.

```
LESS  ASSIGN,XX(4)=XX(4)-ATRIB(2);
```

Decrement shipment received quantity from total backorders if the quantity in the shipment was less than the quantity of backorders.

```
      ACTIVITY,,,END;
```

Entity dies.

IV. Quarterly calculation of forecasted demand, eoq, reorder point, and update of variables

```
      CREATE,,,1,1,1;
      ACTIVITY,91; delay one quarter
```

Create one entity at time zero, it waits one quarter before it triggers recalculation of variables.

```
DATA  COLCT,XX(5),QTRLY DMD;
      ACTIVITY;
```

Collect statistics on quarterly demand.

```
USER  ASSIGN,XX(8)=XX(10)/XX(11),XX(3)=USERF(1),
      XX(7)=USERF(2),XX(5)=0,1;
      ACTIVITY;
```

Compute daily demand rate, new reorder point quantity, and rounded (up) eoq by calling fortran subroutine. Original model did not calculate integer values for EOQ.

```
AVGE  COLCT,XX(7),AVG EOQ,,1;
```

Collect statistics on EOQ.

```
      ACTIVITY,91,,DATA;
```

Entity waits 91 days (one quarter) and is sent back to the create node DATA to begin the process again.

V. Annual computation of TVC and daily average backorders; annual variables cleared.

```
YEAR  CREATE,364,364,,,1;
      ACTIVITY;
      ASSIGN,XX(35)=XX(21)*5.2,XX(23)=XX(23)/365,
      XX(26)=XX(26)/365,XX(24)=XX(35)+XX(36),XX(33)=XX(23),
      XX(34)=XX(26),XX(21)=0,XX(36)=0,XX(23)=0,
      XX(26)=0;
      ACTIVITY;
```

Compute ordering cost, daily on hand inventory, average daily backorders, TVC, VAR statement daily inventory and backorders, clearing of annual variables.

```
CTVC  COLCT,XX(24),TVC,,1;
      ACTIVITY;
CINV  COLCT,XX(33),INV,,1;
      ACTIVITY;
```

```
      ASSIGN,XX(11)=0,XX(10)=0; clear variables
      ACTIVITY;
```

Collect TVC, average inventory, clear day of the year and cumulative annual demand.

```
DONE  TERMINATE;
```

Terminate node.

```
      END;
```

Appendix J: DLA EOQ SLAM Subroutine Fortran Code

Comments are provided (*in italics and under applicable lines of code*) for each section of the model as to its purpose and function, as well as explanation of differences from the original code, if applicable.

```
PROGRAM MAIN
      DIMENSION NSET(1000000)
      PARAMETER(MEQT=100,MSCND=25,MENTR=25,MRSC=75,MARR=50,
     1 MGAT=25,MHIST=50,MCELS=500,MCLCT=50,MSTAT=50,MEQV=100,
     2 MATRB=100,MFILS=100,MPLOT=10,MVARP=10,MSTRM=10,
     3 MACT=100,MNODE=500,MITYP=50,MMXXV=100)
      PARAMETER(MVARP1=MVARP+1)
      COMMON/SCOM1/ATRIB(MATRB),DD(MEQT),DDL(MEQT),DTNOW,II,MFA,
     1 MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(MEQT),
     2 SSL(MEQT),TNEXT,TNOW,XX(MMXXV)
      COMMON QSET(1000000)
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=1000000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      CALL SLAM
      STOP
      END
C
C
      FUNCTION USERF(IFN)
      PARAMETER(MEQT=100,MSCND=25,MENTR=25,MRSC=75,MARR=50,
     1 MGAT=25,MHIST=50,MCELS=500,MCLCT=50,MSTAT=50,MEQV=100,
     2 MATRB=100,MFILS=100,MPLOT=10,MVARP=10,MSTRM=10,
     3 MACT=100,MNODE=500,MITYP=50,MMXXV=100)
      PARAMETER(MVARP1=MVARP+1)
      COMMON/SCOM1/ATRIB(MATRB),DD(MEQT),DDL(MEQT),DTNOW,II,MFA,
     1 MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(MEQT),
     2 SSL(MEQT),TNEXT,TNOW,XX(MMXXV)
C
      GOTO (10,20,30),IFN
C
10    I=XX(8)*XX(6)
      USERF=I
      GOTO 40
```

USERF1 called from model. Calculation of reorder point quantity (daily demand rate times lead time).

```
C
20    R=20.396*(SQRT(XX(14)/XX(15)))
      J=INT(R+.5)
      USERF=J
      GOTO 40
```

USERF2 called from model. Calculation of EOQ plus .5 and truncate to provide integer value.

```
C
30    IF (XX(23).LE.0.) THEN
```

```
      XX(23)=0
      GOTO 39
   ENDIF
```

Artifact from original model; zeroes out cumulative daily on-hand inventory if becomes negative.

```
39    USERF=1
C
40    RETURN
      END
```

End subroutine and return to model.

Appendix K. Silver-Meal SLAM Model

Comments are provided (*in italics and under applicable lines of code*) for each section of the model as to its purpose and function, as well as explanation of differences from the original code, if applicable.

I. Control Statement

```
GEN,Goulet and Rollman,SMM0,9/1/1996,5,N,N,Y/Y,N,Y/1,132;
```

Model authors, title, date, number of runs (1).

```
LIMITS,2,5,100000;
```

Limits statement; number of files, attribute number used, file space required.

```
ARRAY(1,11)/.0000,.3117,.7468,.7987,.8961,.9610,.9611,.9612,.9613,.9614,
      1.0000;
ARRAY(2,11)/1.0,145.6,291.2,436.8,582.4,728.,873.6,1019.2,1164.8,
      1310.4,1456.;
```

Input arrays; time between orders.

```
ARRAY(3,11)/.0000,.7922,.8961,.9545,.9805,.9870,.9935,.9936,.9937,.9938,
      1.0000;
ARRAY(4,11)/1.0,8.78334,17.5667,26.35,35.1333,43.9167,52.7,61.4833,
      70.2666,79.05,87.8333;
```

Input arrays; quantity per demand.

```
SEEDS,53060595(1),49626694(2);
```

Seeds statements for independent starting conditions.

```
INITIALIZE,,72800,Y;
```

Initialize statement; run for 200 years

```
;MONITOR,CLEAR,73000;
;MONITOR,SUMRY,91,91,Y;
```

Inactive monitor clear and summary statements used during model validation process.

```
INTLC,XX(15)=142,XX(6)=190,XX(1)=9
```

Starting conditions; unit price, lead time, on-hand inventory.

```
RECORD,TNOW,TIME,,T,364,,,Y;
```

Record statement; recorded variable, label, table output, interval (days).

```
;VAR,XX(14),Q,QFD;
```

```
;VAR,XX(5),D,ACTUAL;
VAR,XX(33),O,OHINV;
;VAR,XX(4),B,BACKORD;
VAR,XX(24),T,TVC;
```

Variable statements; Variable of interest, plot label, output label.

```
TIMST,XX(1),XX1 OH INV
TIMST,XX(2),XX2 START EOQ
TIMST,XX(3),XX3 ROPTIMST,XX(4),XX4 AVG BO
TIMST,XX(5),XX5 QRTLY DMD
TIMST,XX(7),XX7 USERF2 EOQ
TIMST,XX(8),XX8 DDR
TIMST,XX(9),XX9PPLN INV
TIMST,XX(10),XX10CUM DEMAND
TIMST,XX(11),XX11CUM DAYS
TIMST,XX(14),XX14QFD
TIMST,XX(21),XX21ORDERS PLACED
TIMST,XX(22),XX22DAIL CAR CST
TIMST,XX(36),XX36CUM CAR COST
TIMST,XX(23),XX23AVG ANN INV
TIMST,XX(24),XX24TVC
TIMST,XX(25),XX25DAYS INV TAKEN
TIMST,XX(26),XX26QT1 VALUE;
TIMST,XX(27),XX27QT2 VALUE;
TIMST,XX(28),XX28QT3 VALUE;
TIMST,XX(36),XX36CUM CARCOST;
TIMST,XX(51),XX51SMT1
TIMST,XX(52),XX52SMT2
TIMST,XX(53),XX53SMT3
```

Initiation of measurement for time persistent variables.

```
NETWORK;
```

Network statement; Calls SLAM network.

II. Demand Generation and Issue/Backorder Process

```
DMND  CREATE;
      ACTIVITY;
      ASSIGN,XX(60)=DRAND(5),XX(61)=GGTBLN(1,2,XX(60));
      ACTIVITY,XX(61),,DMND;
      ACTIVITY,,,QTY;
```

Demand creation; One entity created, calls empirical arrays for time between order, entity runs assigned time, reenters create node to begin process again. Cloned entity from assign node sent to QTY assign node for calculation of quantity per demand.

```
QTY   ASSIGN,XX(62)=DRAND(5),XX(63)=GGTBLN(3,4,XX(62)),XX(99)=XX(63)+0.5,
      II=XX(99),ATRIB(5)=II;
```

Quantity per demand assignment; entity assigned quantity from second set of empirical arrays, number truncated, quantity assigned to attribute.

```
      ACTIVITY,91,,TIM;
```

Batched entity sent one quarter into the future to provide identical demand frequencies and quantities.

```
      ACTIVITY,,,DDR;
```

Send cloned entity to udate forecasted demand variable used in subroutine to calculate EOQ.

```
DDR   UNBATCH,5,1;
      ACTIVITY;
QTR   ASSIGN,XX(14)=XX(14)+1,1;
      ACTIVITY,,,END;
```

Unbatch order quanity and update forecasted demand variable. Entity terminates.

```
TIM   UNBATCH,5,1;
      ACTIVITY,,,TOM;
```

Unbatch order quantity to initiate fill or backorder process.

```
TOM   ASSIGN,XX(5)=XX(5)+1,1;
```

Increment quarterly demand by number of entities in order.

```
      ACTIVITY,,XX(1).GT.0.;
```

If there sufficient inventory to fill requisition from shelf, go to the issue inventory node.

```
      ACTIVITY,,,BACK;
```

If not, go to the back order node.

```
INV   ASSIGN,XX(1)=XX(1)-1,1;
```

Issue and decrement on hand inventory counter.

```
      ACTIVITY;
END   TERMINATE;
```

Entity dies.

```
BACK  ASSIGN,XX(4)=XX(4)+1,1;
```

Increment number of backorders.

```
      ACTIVITY,,,END;
```

Entity dies.

III. Variable Update Process

```
REPL  CREATE,1,,1,,2;
      ACTIVITY;
      ACTIVITY,,,INFO;
ZAAB  ASSIGN,XX(25)=.1/364,XX(22)=XX(1)*XX(15)*XX(25),
      XX(36)=XX(36)+XX(22),XX(22)=0,XX(23)=XX(23)+XX(1);
      ACTIVITY,,,END;
```

Calculate daily holding rate, daily holding cost, cumulative holding cost, clear daily, increment cumulative inventory.

IV. Quarterly Update of Silver-Meal Variables and Order Placement

```
SMM    CREATE,91,,1,,1;
       ACTIVITY;
```

Create only one entity 91 days into the simulation to trigger the Silver-Meal ordering process and recalculation of variables.

```
QT1    ASSIGN,ATRIB(2)=XX(26),2;
       ACTIVITY,XX(6),,REN1;
```

Order the quantity calculated by the FORTRAN Silver-Meal heuristic for the first month of present quarter. Wait lead-time for order arrival and go to order receipt node REN1.

```
       ACTIVITY,30,,QT2;
```

Send cloned quantity on 30 day trek to second month order node

```
       ACTIVITY,,ATRIB(2).GT.0,ORDR;
```

If monthly order quantity is calculated at 0, don't increment orders placed variable.

```
REN1   GOON,1;
       ACTIVITY/24,,ATRIB(2).GE.XX(4),MORE;
```

If quantity received is greater than backorder quantity, go to MORE node.

```
       ACTIVITY/25,,,LESS;
```

If quantity received is less than backorder quantity, go to LESS node.

```
MORE   ASSIGN,XX(1)=XX(1)+ATRIB(2)-XX(4),XX(4)=0,1;
```

Increment on-hand inventory by shipment received quantity then decrement by backorder quantity if quantity in the shipment was more than the quantity of backorders.

```
       ACTIVITY,,,END;
```

Entity dies.

```
LESS   ASSIGN,XX(4)=XX(4)-ATRIB(2);
```

Decrement shipment received quantity from total backorders if the quantity in the shipment was less than the quantity of backorders.

```
       ACTIVITY,,,END;
```

Entity dies.

```
QT2    ASSIGN,ATRIB(2)=XX(27),2;
       ACTIVITY,XX(6),ATRIB(2).GT.0,REN1;
```

Order the quantity calculated by the FORTRAN Silver-Meal heuristic for the second month of present quarter if there was, in fact, an order quantity calculated. Wait lead-time for order arrival and go to order receipt node REN1.

```
       ACTIVITY,30,,QT3;
```

Send cloned quantity on 30 day trek to third month order node

```
ACTIVITY,,ATRIB(2).GT.0,ORDR;
```

If monthly order quantity is greater than 0, increment orders placed variable.

```
QT3   ASSIGN,ATRIB(2)=XX(28),2;
ACTIVITY/28,XX(6),ATRIB(2).GT.0,REN1; goto REN1
```

Order the quantity calculated by the FORTRAN Silver-Meal heuristic for the third month of present quarter if there was, in fact, an order quantity calculated. Wait lead-time for order arrival and go to order receipt node REN1.

```
ACTIVITY,,ATRIB(2).GT.0,ORDR;
```

If monthly order quantity is calculated at 0, don't increment orders placed variable.

```
ACTIVITY,,,END;
```

Send cloned quantity to END terminate node

```
ORDR  ASSIGN,XX(21)=XX(21)+1;
      ACTIVITY,,,END;
```

Increment cumulative order quantity. Entity dies.

V. Annual computation of TVC and daily average backorders; annual variables cleared.

```
YEAR  CREATE,364,364,,,1;
      ACTIVITY;
      ASSIGN,XX(35)=XX(21)*5.2,XX(24)=XX(35)+XX(36),XX(23)=XX(23)/365,
      XX(21)=0,XX(33)=XX(23),XX(36)=0,XX(21)=0,XX(23)=0;
      ACTIVITY;
```

Compute ordering cost and daily on hand inventory, and TVC, clearing of annual variables.

```
CTVC  COLCT,XX(24),TVC,,1;
      ACTIVITY;
```

Collect TVC.

```
CINV  COLCT,XX(33),INV,,1;
      ACTIVITY;
```

Collect average inventory.

```
DONE  TERMINATE;
```

Terminate node.

```
      END;
FIN
```

Appendix L: Silver-Meal SLAM Subroutine Fortran Code

Comments are provided (*in italics and under applicable lines of code*) for each section of the model as to its purpose and function

```
PROGRAM MAIN
      DIMENSION NSET(1000000)
      PARAMETER (MEQT=100,MSCND=25,MENTR=25,MRSC=75,MARR=50,
     1 MGAT=25,MHIST=50,MCELS=500,MCLCT=50,MSTAT=50,MEQV=100,
     2 MATRB=100,MFILS=100,MPLOT=10,MVARP=10,MSTRM=10,
     3 MACT=100,MNODE=500,MITYP=50,MMXXV=100)
      PARAMETER(MVARP1=MVARP+1)
      COMMON/SCOM1/ATRIB(MATRB),DD(MEQT),DDL(MEQT),DTNOW,II,MFA,
     1 MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(MEQT),
     2 SSL(MEQT),TNEXT,TNOW,XX(MMXXV)
      COMMON QSET(1000000)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=1000000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      CALL SLAM
      STOP
      END
C
C
      FUNCTION USERF(IFN)
      PARAMETER(MEQT=100,MSCND=25,MENTR=25,RSC=75,MARR=50,
     1 MGAT=25,MHIST=50,MCELS=500,MCLCT=50,MSTAT=50,MEQV=100,
     2 MATRB=100,MFILS=100,MPLOT=10,MVARP=10,MSTRM=10,
     3 MACT=100,MNODE=500,MITYP=50,MMXXV=100)
      PARAMETER (MVARP1=MVARP+1)
      COMMON/SCOM1/ATRIB(MATRB),DD(MEQT),DDL(MEQT),DTNOW,II,MFA,
     1 MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(MEQT),
     2 SSL(MEQT),TNEXT,TNOW,XX(MMXXV)
      GOTO (10,20,30,40),IFN
C
10    I=XX(8)*XX(6)
      USERF=I
      GOTO 50
20    J=20.396*(SQRT(XX(14)/XX(15)))
      USERF=J
      GOTO 50
C
```

Calculation of Monthly Order Quantity

```
C
30    XX(51)=5.20
```

Set variable equal to ordering cost.

```
      XX(31)=XX(15)*(.1/12)
```

Set variable equal to unit price times one month's holding rate to equal cost of holding one month's worth of inventory

```
      XX(52)=(XX(51)+((XX(14)/3)*XX(31)))/2
```

Set variable equal to ordering cost plus cost of holding one month's worth of inventory

```
      XX(53)=(XX(51)+((XX(14)/3)*(XX(31)))+(((2*XX(14))/3)*(XX(31))))/3
```

Set variable equal to ordering cost plus cost of holding 2 month's worth of inventory.

```
      IF (XX(52).GT.XX(51)) GOTO 31
      GOTO 32
31    IF (XX(53).GT.XX(52)) GOTO 36
      GOTO 32
32    IF (XX(52).LT.XX(51)) GOTO 33
      GOTO 34
33    IF (XX(53).GT.XX(52)) GOTO 37
      GOTO 34
34    IF (XX(53).LT.XX(51)) GOTO 35
      GOTO 38
35    IF (XX(53).LT.XX(52)) GOTO 38
      GOTO 38
```

Series of IF statements to select lowest cost ordering policy for the next quarter.

```
36    XX(26)=XX(14)/3
      XX(27)=XX(14)/3
      XX(28)=XX(14)/3
      XX(26)=INT(XX(26)+.5)
      XX(27)=INT(XX(27)+.5)
      XX(28)=INT(XX(28)+.5)
      XX(21)=XX(21)+3
      GOTO 39
```

Order one month's worth of inventory each month of the quarter. Round up and truncate order quantities.

```
37    XX(26)=(2*XX(14))/3
      XX(27)=0
      XX(28)=XX(14)/3
      XX(26)=INT(XX(26)+.5)
      XX(28)=INT(XX(28)+.5)
      XX(21)=XX(21)+2
      GOTO 39
```

Order 2 month's worth of inventory the first month and one month's worth the third month..

```
38    XX(26)=XX(14)
      XX(27)=0
      XX(28)=0
      XX(26)=INT(XX(26)+.5)
      XX(21)=XX(21)+1
      GOTO 39
```

Order 3 month's worth of inventory the first month.

```
39    USERF=1
      GOTO 50
40    IF (XX(23).LE.0) GOTO 41
      GOTO 49
41    XX(23)=0
49    USERF=1
50    RETURN
```

Return to SLAM model.

```
      END
```

End FORTRAN subroutine.

Appendix M. Periodic Order Quantity SLAM Model

Comments are provided (*in italics and under applicable lines of code*) for each section of the model as to its purpose and function

```
GEN,Goulet and Rollman,POQ0,9/1/1996,5,N,N,Y/Y,N,Y/1,132;
```

Model authors, title, date, number of runs.

```
LIMITS,2,5,100000;
```

Limits statement; number of files, attribute number used, file space required.

```
ARRAY(1,11)/.0000,.3117,.7468,.7987,.8961,.9610,.9611,.9612,.9613,.9614,
      1.0000;
ARRAY(2,11)/1,145.6,291.2,436.8,582.4,728.,873.6,1019.2,
      1164.8,1310.4,1456.;
```

Input arrays: time between orders.

```
ARRAY(3,11)/.0000,.7922,.8961,.9545,.9805,.9870,.9935,.9936,.9937,.9938,
      1.0000;
ARRAY(4,11)/1,8.78334,17.5667,26.35,35.1333,43.9167,52.7,
      61.4833,70.2666,79.05,87.8333;
```

Input arrays; quantity per demand.

```
SEEDS,53060595(1),49626694(2);
```

Seeds statement for independent starting conditions

```
INITIALIZE,,72800,Y;
```

Initialize statement; run for 200 years

```
;MONITOR,CLEAR,73000;
;MONITOR,SUMRY,91,91,Y;
```

Monitor clear and summary statements.

```
INTLC,XX(15)=141,XX(6)=190,XX(1)=9;
```

Starting conditions; unit price, lead time, on-hand inventory.

```
RECORD,TNOW,TIME,,T,364,,,Y;
```

Record statement; recorded variable, label, table output, interval (days).

```
VAR,XX(33),I,AVGINV;
VAR,XX(24),T,TVC;
;VAR,XX(5),D,ACTUAL;
;VAR,XX(1),O,OHINV;
;VAR,XX(4),B,BACKORD;
```

Variable statements; Variable of interest, plot label, output label.

```
TIMST,XX(1),XX1 OH INV;
TIMST,XX(33),XX33 AVGINV;
TIMST,XX(24),XX24 TVC;
;TIMST,XX(4),XX4 AVG BO;
;TIMST,XX(5),XX5 ACTUAL;
;TIMST,XX(14),XX14FCSTDMD;
;TIMST,XX(21),XX21ORDERS PLACED;
;TIMST,XX(26),XX26QT1 VALUE;
;TIMST,XX(27),XX27QT2 VALUE;
;TIMST,XX(28),XX28QT3 VALUE;
;TIMST,XX(51),XX51POQ1;
;TIMST,XX(52),XX52POQ2;
;TIMST,XX(53),XX53POQ3;
;TIMST,XX(70),XX70;
;TIMST,XX(71),XX71PERIOD;
;TIMST,XX(72),XX72VALUE;
NETWORK;
```

Initiation of measurement for time persistent variables.

```
;
WAYNE CREATE,,1,,1;
      ACTIVITY; Created demand
B1AD  ASSIGN,XX(60)=DRAND(2),XX(61)=GGTBLN(1,2,XX(60));
      ACTIVITY,XX(61),,WAYNE;
      ACTIVITY,,,MIKE;
```

Demand creation; One entity created, calls empirical arrays for time between order, entity runs assigned time, reenters create node to begin process again. Cloned entity from assign node sent to QTY assign node for calculation of quantity per demand.

```
MIKE  ASSIGN,XX(62)=DRAND(2),XX(63)=GGTBLN(3,4,XX(62)),XX(99)=XX(63)+0.5,
      II=XX(99),ATRIB(5)=II,2;
```

Quantity per demand assignment; entity assigned quantity from second set of empirical arrays, number truncated, quantity assigned to attribute.

```
      ACTIVITY,91,,TIM;
```

Batched entity sent one quarter into the future to provide identical demand frequencies and quantities.

```
      ACTIVITY/4,,,DDR;
```

Send cloned entity to update forecasted demand variable used in subroutine to calculate EOQ.

```
DDR   UNBATCH,5,1;
      ACTIVITY;
QTR   ASSIGN,XX(14)=XX(14)+1,1;
      ACTIVITY,,,END;
```

Unbatch order quantity and update forecasted demand variable. Entity terminates.

```
TIM   UNBATCH,5,1;
      ACTIVITY,,,TOM;
```

Unbatch order quantity to initiate fill or backorder process.

```
TOM   ASSIGN,XX(5)=XX(5)+1,1;
```

Increment quarterly demand by number of entities in order.

```
      ACTIVITY,,XX(1).GT.0.;
```

If there sufficient inventory to fill requisition from shelf, go to the issue inventory node.

```
      ACTIVITY,,,BACK;
```

If not, go to the back order node.

```
INV   ASSIGN,XX(1)=XX(1)-1,1;
```

Issue and decrement on hand inventory counter.

```
      ACTIVITY;
END   TERMINATE;
```

Entity dies.

```
BACK  ASSIGN,XX(4)=XX(4)+1,1;
      ACTIVITY,,,END;
```

Increment number of backorders; entity dies.

;

III. Variable Update Process

```
;
REPL  CREATE,1,,1,,2;
      ACTIVITY;
      ACTIVITY,,,INFO;
      ASSIGN,XX(25)=.1/365,XX(22)=XX(1)*XX(15)*XX(25),
      XX(36)=XX(36)+XX(22),XX(23)=XX(23)+XX(1);
      ACTIVITY,,,END;
```

Calculate daily holding rate, daily holding cost, cumulative holding cost, clear daily, increment cumulative inventory.

```
INFO  COLCT,XX(1),AVG INV;
      ACTIVITY,,,END;
```

Collect node for on-hand inventory.

;

IV. Quarterly Update of Periodic Order Quantity Variables

```
;
SMM   CREATE,91,,1,,1;
      ACTIVITY;
```

Create only one entity 91 days into the simulation to trigger the Periodic Order Quantity ordering process and recalculation of variables.

```
      ASSIGN,XX(70)=XX(14)/3,XX(71)=USERF(2),XX(14)=0,XX(5)=0;
```

Initiate order quantity calculations by the FORTRAN Periodic Order Quantity code using projected demand from arrays..

```
QT1   ASSIGN,ATRIB(2)=XX(26),3;
      ACTIVITY,XX(6),,REN1;
```

Order the quantity calculated for the first month of present quarter. Wait lead-time for order arrival and go to order receipt node REN1.

```
       ACTIVITY,30,,QT2;
```

Send cloned quantity on 30 day trek to second month order node

```
       ACTIVITY,,ATRIB(2).GT.0,ORDR;
```

If monthly order quantity is calculated at 0, don't increment orders placed variable.

```
REN1   GOON,1;
       ACTIVITY,,ATRIB(2).GE.XX(4),MORE;
```

If quantity received is greater than backorder quantity, go to MORE node.

```
       ACTIVITY,,,LESS;
```

If quantity received is less than backorder quantity, go to LESS node.

```
MORE   ASSIGN,XX(1)=XX(1)+ATRIB(2)-XX(4),XX(4)=0,1;
```

Increment on-hand inventory by shipment received quantity then decrement by backorder quantity if quantity in the shipment was more than the quantity of backorders.

```
       ACTIVITY,,,END;
```

Entity dies.

```
LESS   ASSIGN,XX(4)=XX(4)-ATRIB(2);
```

Decrement shipment received quantity from total backorders if the quantity in the shipment was less than the quantity of backorders.

```
       ACTIVITY,,,END;
```

Entity dies.

```
QT2    ASSIGN,ATRIB(2)=XX(27),3;
       ACTIVITY,XX(6),ATRIB(2).GT.0,REN1;
```

Order the quantity calculated for the second month of present quarter. Wait lead-time for order arrival and go to order receipt node REN1.

```
       ACTIVITY,30,,QT3;
```

Send cloned quantity on 30 day trek to third month order node

```
       ACTIVITY,,ATRIB(2).GT.0,ORDR;
```

If monthly order quantity is calculated at 0, don't increment orders placed variable.

```
QT3    ASSIGN,ATRIB(2)=XX(28),3;
       ACTIVITY,XX(6),ATRIB(2).GT.0,REN1;
```

Order the quantity calculated for the third month of present quarter. Wait lead-time for order arrival and go to order receipt node REN1.

```
       ACTIVITY,,,END;
```

Send cloned quantity to END terminate node

```
      ACTIVITY,,ATRIB(2).GT.0,ORDR;
```

If monthly order quantity is calculated at 0, don't increment orders placed variable.

```
ORDR  ASSIGN,XX(21)=XX(21)+1;
      ACTIVITY,,,END;
```

Increment cumulative order quantity. Entity dies.

```
;
```

V. Annual Computation of TVC and Daily Average Backorders.

```
;
YEAR  CREATE,364,364,,,1;
      ACTIVITY;
      ASSIGN,XX(35)=XX(21)*5.2,XX(23)=XX(23)/365,XX(33)=XX(23),
      XX(24)=XX(35)+XX(36),XX(21)=0,XX(36)=0,XX(23)=0;
      ACTIVITY;
```

Compute ordering cost and daily on hand inventory, and TVC, clearing of annual variables.

```
CTVC  COLCT,XX(24),TVC,,1; total variable cost statistics
      ACTIVITY;
CINV  COLCT,XX(33),INV,,1; average inv
```

Collect TVC and average inventory.

```
      ACTIVITY;
DONE  TERMINATE;
```

Terminate node.

```
;
      END;
FIN
```

Appendix N. Periodic Order Quantity FORTRAN Subroutine

Comments are provided (*in italics and under applicable lines of code*) for each section of the model as to its purpose and function.

```
PROGRAM MAIN
      DIMENSION NSET(1000000)
      PARAMETER (MEQT=100,MSCND=25,MENTR=25,MRSC=75,MARR=60,
     1 MGAT=25,MHIST=60,MCELS=500,MCLCT=60,MSTAT=60,MEQV=100,
     2 MATRB=100,MFILS=100,MPLOT=10,MVARP=10,MSTRM=10,
     3 MACT=100,MNODE=500,MITYP=60,MMXXV=100,MMXFLD=100)
      PARAMETER(MVARP1=MVARP+1)
      COMMON/SCOM1/ATRIB(MATRB),DD(MEQT),DDL(MEQT),DTNOW,II,MFA,
     1 MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(MEQT),
     2 SSL(MEQT),TNEXT,TNOW,XX(MMXXV)
      COMMON QSET(1000000)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=1000000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      CALL SLAM
      STOP
      END
C
      FUNCTION USERF(IFN)
      PARAMETER(MEQT=100,MSCND=25,MENTR=25,RSC=75,MARR=60,
     1 MGAT=25,MHIST=60,MCELS=500,MCLCT=60,MSTAT=60,MEQV=100,
     2 MATRB=100,MFILS=100,MPLOT=10,MVARP=10,MSTRM=10,
     3 MACT=100,MNODE=500,MITYP=60,MMXXV=100,MMXFLD=100)
      PARAMETER (MVARP1=MVARP+1)
      COMMON/SCOM1/ATRIB(MATRB),DD(MEQT),DDL(MEQT),DTNOW,II,MFA,
     1 MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(MEQT),
     2 SSL(MEQT),TNEXT,TNOW,XX(MMXXV)
      GOTO (10,20,30,40),IFN
C
C
   10 I=XX(8)*XX(6)
      USERF=I
      GOTO 50
   20 IF (XX(70).EQ.0) GOTO 35
      R=SQRT(((2)*(5.2))/(XX(70)*XX(15)*.025))
      XX(72)=R
      J=INT(R+.5)
      USERF=J
      GOTO 30
```

Calculation of Periodic Order Quantity decision variable.

```
C
```

Calculation of Monthly Order Quantity

```
   30 IF (XX(71).EQ.1) GOTO 36
      GOTO 31
   31 IF (XX(71).EQ.2) GOTO 37
      GOTO 32
   32 IF (XX(71).EQ.3) GOTO 38
   35 XX(26)=0
```

```
      XX(27)=0
      XX(28)=0
      GOTO 39
   36 XX(26)=XX(70)
      XX(27)=XX(70)
      XX(28)=XX(70)
      XX(26)=INT(XX(26)+.5)
      XX(27)=INT(XX(27)+.5)
      XX(28)=INT(XX(28)+.5)
      GOTO 39
```

Order one month's worth of inventory each month of the quarter. Round up and truncate order quantities.

```
   37 XX(26)=(2*XX(70))
      XX(27)=0.0
      XX(28)=XX(70)
      XX(26)=INT(XX(26)+.5)
      XX(27)=INT(XX(27)+.5)
      XX(28)=INT(XX(28)+.5)
      GOTO 39
```

Order 2 month's worth of inventory the first month and one month's worth the third month..

```
   38 XX(26)=(3*XX(70))
      XX(27)=0.0
      XX(28)=0.0
      XX(26)=INT(XX(26)+.5)
      XX(27)=INT(XX(27)+.5)
      XX(28)=INT(XX(28)+.5)
      GOTO 39
```

Order 3 month's worth of inventory the first month.

```
   39 USERF=1
   40 IF (XX(23).LE.0) GOTO 41
      GOTO 49
   41 XX(23)=0
   49 USERF=1
   50 RETURN
```

Return to SLAM model.

```
      END
```

End FORTRAN subroutine.

Appendix O. Verification of the Silver-Meal Model

To verify the Silver-Meal model, mean values for each SMCC's TBO and QPD were inserted into the respective create nodes of the computer model. The performance of the computer model was verified by running the models for one year and collecting the total relevant cost (TRUC) calculations every quarter. This output was compared to results that were calculated analytically. Model verification was completed when computer output based on the mean input agreed with first-year analytical results. The analytic calculations and simulation output for the TRUC of SMCC 5 are presented below (for this SMCC, TBO was 51 days and QPD was 7 units):

Variables Used to Validate the Silver-Meal Model

Variable	Description
XX(5)	Actual Demand (current quarter)
XX(14)	Forecasted Demand (next quarter)
XX(15)	Unit price (*v*)
XX(26)	Silver Meal order quantity - 1st month of quarter
XX(27)	Silver Meal order quantity - 2nd month of quarter
XX(28)	Silver Meal order quantity - 3rd month of quarter
XX(51)	Silver Meal TRUC costs - Month 1
XX(52)	Silver Meal TRUC costs - Month 2
XX(53)	Silver Meal TRUC costs - Month 3
A	Ordering cost
r	Annual holding cost

Sequential Steps to Calculate TRUC

Step	Calculation
1	XX(51) = A/1
2	XX(52) = [A + ((XX(14)/3) * (1) * XX(15) * *r*/12)]/2
3	XX(53) = [(A + ((XX(14)/3) * (1) * XX(15) * *r*/12)) + ((XX(14)/3) * (2) * XX(15) * *r*/12)]/3

1. Validation of Quarter One (SMCC 5)

TRUC Calculation (Qtr 1)

Step	Variable	Result
1	XX(51)	5.20/1 = 5.20
2	XX(52)	[5.20 + ((7/3) * (1) * 1409 * 0.10/12)]/2 = 16.299
3	XX(53)	[(5.20 + ((7/3) * (1) *1409 * 0.10/12)) + ((7/3) * (2) * 1409 * 0.10/12)]/3 = 29.131

Note: XX(51) < XX(52) < XX(53). Place order every month during the quarter. Order quantity is 7/3 or 2.33 units. When rounded, this order quantity is 2 units per month.

Computer Simulation Output (Qtr 1)

```
S L A M   I I   S U M M A R Y   R E P O R T
**STATISTICS FOR TIME-PERSISTENT VARIABLES**

                    MEAN          STANDARD      MINIMUM       MAXIMUM       CURRENT
                    VALUE         DEVIATION     VALUE         VALUE         VALUE
XX5 ACTUAL        0.1538E+01    0.2899E+01    0.0000E+00    0.7000E+01    0.7000E+01
XX14QFD           0.5731E+01    0.4784E+01    0.0000E+00    0.1400E+02    0.1400E+02
XX26QT1 VALUE     0.2000E+01    0.0000E+00    0.0000E+00    0.2000E+01    0.2000E+01
XX27QT2 VALUE     0.2000E+01    0.0000E+00    0.0000E+00    0.2000E+01    0.2000E+01
XX28QT3 VALUE     0.2000E+01    0.0000E+00    0.0000E+00    0.2000E+01    0.2000E+01
XX51SMT1          0.5200E+01    0.0000E+00    0.0000E+00    0.5200E+01    0.5200E+01
XX52SMT2          0.1630E+02    0.0000E+00    0.0000E+00    0.1630E+02    0.1630E+02
XX53SMT3          0.2913E+02    0.9537E-06    0.0000E+00    0.2913E+02    0.2913E+02
```

2. Validation of Quarter Two (SMCC 5)

TRUC Calculation (Qtr 2)

Step	Variable	Result
1	XX(51)	5.20/1 = 5.20
2	XX(52)	[5.20 + ((14/3) * (1) * 1409 * 0.10/12)]/2 = 29.997
3	XX(53)	[(5.20 + ((14/3) * (1) *1409* 0.10/12)) + ((14/3) * (2) * 1409 * 0.10/12)]/3 = 56.528

Note: XX(51) < XX(52) < XX(53). Place order every month during the quarter. Order quantity is 14/3 or 4.67 units. When rounded, this order quantity is 5 units per month.

Computer Simulation Output (Qtr 2)

```
S L A M   I I   S U M M A R Y   R E P O R T
**STATISTICS FOR TIME-PERSISTENT VARIABLES**

                    MEAN          STANDARD      MINIMUM       MAXIMUM       CURRENT
                    VALUE         DEVIATION     VALUE         VALUE         VALUE
XX5 ACTUAL        0.3821E+01    0.4749E+01    0.0000E+00    0.1400E+02    0.1400E+02
XX14QFD           0.6051E+01    0.4755E+01    0.0000E+00    0.1400E+02    0.1400E+02
XX26QT1 VALUE     0.3000E+01    0.1414E+01    0.0000E+00    0.5000E+01    0.5000E+01
XX27QT2 VALUE     0.3000E+01    0.1414E+01    0.0000E+00    0.5000E+01    0.5000E+01
XX28QT3 VALUE     0.3000E+01    0.1414E+01    0.0000E+00    0.5000E+01    0.5000E+01
XX51SMT1          0.5200E+01    0.0000E+00    0.0000E+00    0.5200E+01    0.5200E+01
XX52SMT2          0.2086E+02    0.6458E+01    0.0000E+00    0.3000E+02    0.3000E+02
XX53SMT3          0.3826E+02    0.1292E+02    0.0000E+00    0.5653E+02    0.5653E+02
```

3. Validation of Quarter Three (SMCC 5)

TRUC Calculation (Qtr 3)

Step	Variable	Result
1	XX(51)	5.20/1 = 5.20
2	XX(52)	[5.20 + ((14/3) * (1) * 1409 * 0.10/12)]/2 = 29.997
3	XX(53)	[(5.20 + ((14/3) * (1) *1409* 0.10/12)) + ((14/3) * (2) * 1409 * 0.10/12)]/3 = 56.528

Note: XX(51) < XX(52) < XX(53). Place order every month during the quarter. Order quantity is 14/3 or 4.67 units. When rounded, this order quantity is 5 units per month.

Computer Simulation Output (Qtr 3)

```
S L A M   I I   S U M M A R Y   R E P O R T
**STATISTICS FOR TIME-PERSISTENT VARIABLES**

                    MEAN          STANDARD      MINIMUM       MAXIMUM       CURRENT
                    VALUE         DEVIATION     VALUE         VALUE         VALUE
XX5 ACTUAL        0.4538E+01    0.4881E+01    0.0000E+00    0.1400E+02    0.1400E+02
XX14QFD           0.5788E+01    0.4642E+01    0.0000E+00    0.1400E+02    0.1400E+02
XX26QT1 VALUE     0.3500E+01    0.1500E+01    0.0000E+00    0.5000E+01    0.5000E+01
XX27QT2 VALUE     0.3500E+01    0.1500E+01    0.0000E+00    0.5000E+01    0.5000E+01
XX28QT3 VALUE     0.3500E+01    0.1500E+01    0.0000E+00    0.5000E+01    0.5000E+01
XX51SMT1          0.5200E+01    0.0000E+00    0.0000E+00    0.5200E+01    0.5200E+01
XX52SMT2          0.2315E+02    0.6849E+01    0.0000E+00    0.3000E+02    0.3000E+02
XX53SMT3          0.4283E+02    0.1370E+02    0.0000E+00    0.5653E+02    0.5653E+02
```

4. Validation of Quarter Four (SMCC 5)

TRUC Calculation (Qtr 4)

Step	Variable	Result
1	XX(51)	5.20/1 = 5.20
2	XX(52)	[5.20 + ((14/3) * (1) * 1409 * 0.10/12)]/2 = 29.997
3	XX(53)	[(5.20 + ((14/3) * (1) *1409* 0.10/12)) + ((14/3) * (2) * 1409 * 0.10/12)]/3 = 56.528

Note: XX(51) < XX(52) < XX(53). Place order every month during the quarter. Order quantity is 14/3 or 4.67 units. When rounded, this order quantity is 5 units per month.

Computer Simulation Output (Qtr 4)

```
S L A M   I I   S U M M A R Y   R E P O R T
**STATISTICS FOR TIME-PERSISTENT VARIABLES**

                    MEAN          STANDARD      MINIMUM       MAXIMUM       CURRENT
                    VALUE         DEVIATION     VALUE         VALUE         VALUE
XX5 ACTUAL        0.4631E+01    0.4754E+01    0.0000E+00    0.1400E+02    0.1400E+02
XX14QFD           0.5354E+01    0.4522E+01    0.0000E+00    0.1400E+02    0.7000E+01
XX26QT1 VALUE     0.3800E+01    0.1470E+01    0.0000E+00    0.5000E+01    0.5000E+01
XX27QT2 VALUE     0.3800E+01    0.1470E+01    0.0000E+00    0.5000E+01    0.5000E+01
XX28QT3 VALUE     0.3800E+01    0.1470E+01    0.0000E+00    0.5000E+01    0.5000E+01
XX51SMT1          0.5200E+01    0.0000E+00    0.0000E+00    0.5200E+01    0.5200E+01
XX52SMT2          0.2452E+02    0.6711E+01    0.0000E+00    0.3000E+02    0.3000E+02
XX53SMT3          0.4557E+02    0.1342E+02    0.0000E+00    0.5653E+02    0.5653E+02
```

Appendix P. Verification of the Periodic Order Quantity

To verify the Periodic Order Quantity (POQ) model, mean values for each SMCC's TBO and QPD were inserted into the respective create nodes of the computer model. The performance of the computer model was verified by running the models for one year and collecting the EOQ value (expressed as a time supply using $\overline{D}$) every quarter. This simulation output value was then compared to results that were calculated analytically. Model verification was completed when computer output based on the mean input agreed with first-year analytical results. The analytic calculations and simulation output for the time supply EOQ value are presented below (for this SMCC, TBO was 51 days and QPD was 7 units):

Variables Used to Validate the POQ Model

Variable	Description
XX(5)	Actual Demand (current quarter)
XX(14)	Forecasted Demand (next quarter)
XX(15)	Unit price (*v*)
XX(26)	Periodic order quantity - 1st month of quarter
XX(27)	Periodic order quantity - 2nd month of quarter
XX(28)	Periodic order quantity - 3rd month of quarter
XX(70)	Average monthly demand (current quarter)
XX(71)	EOQ value expressed as a time supply using $\overline{D}$ (rounded value)
XX(72)	EOQ value expressed as a time supply using $\overline{D}$ (raw value)
A	Ordering cost
r	Annual holding cost

Formula to Calculate Periodic Order Quantity Value

Calculation
$\mathrm{XX}(72) = \sqrt{\dfrac{(2 \ * \ \mathrm{A})}{((\mathrm{XX}(14)/3) \ * \ \mathrm{XX}(15) \ * \ ((.1/12)*3)}}$

1. Validation of Quarter One (SMCC 5)

POQ Calculation (Qtr 1)

Calculation
$XX(72) = \sqrt{\dfrac{(2 \ * \ 5.2)}{((XX(7)/3) \ * \ XX(15) \ * \ ((.1/12)*3)}} \quad = 0.35571$

Note: XX(72) is rounded up to 1. Place an order every month during the quarter. Order quantity is 7/3 or 2.33 units. When rounded, this order quantity is 2 units per month.

Computer Simulation Output (Qtr 1)

S L A M   I I   S U M M A R Y   R E P O R T

****STATISTICS FOR TIME-PERSISTENT VARIABLES****

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	CURRENT VALUE
XX5 ACTUAL	0.1538E+01	0.2899E+01	0.0000E+00	0.7000E+01	0.7000E+01
XX14FCSTDMD	0.5731E+01	0.4784E+01	0.0000E+00	0.1400E+02	0.1400E+02
XX26QT1 VALUE	0.1000E+01	0.1000E+01	0.0000E+00	0.2000E+01	0.2000E+01
XX27QT2 VALUE	0.1000E+01	0.1000E+01	0.0000E+00	0.2000E+01	0.2000E+01
XX28QT3 VALUE	0.1000E+01	0.1000E+01	0.0000E+00	0.2000E+01	0.2000E+01
XX70	0.2333E+01	0.0000E+00	0.0000E+00	0.2333E+01	0.2333E+01
XX71PERIOD	0.1000E+01	0.0000E+00	0.0000E+00	0.1000E+01	0.1000E+01
XX72VALUE	0.3557E+00	0.0000E+00	0.0000E+00	0.3557E+00	0.3557E+00

2. Validation of Quarter Two (SMCC 5)

POQ Calculation (Qtr 2)

Calculation
$XX(72) = \sqrt{\dfrac{(2 \ * \ 5.2)}{((14/3) \ * \ 1409 \ * \ ((.1/12)*3)}} \quad = 0.25152$

Note: XX(72) is rounded up to 1. Place an order every month during the quarter. Order quantity is 14/3 or 4.67 units. When rounded, this order quantity is 5 units per month.

Computer Simulation Output (Qtr 2)

S L A M   I I   S U M M A R Y   R E P O R T

****STATISTICS FOR TIME-PERSISTENT VARIABLES****

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	CURRENT VALUE
XX5 ACTUAL	0.3821E+01	0.4749E+01	0.0000E+00	0.1400E+02	0.1400E+02
XX14FCSTDMD	0.6051E+01	0.4755E+01	0.0000E+00	0.1400E+02	0.1400E+02
XX26QT1 VALUE	0.2333E+01	0.2055E+01	0.0000E+00	0.5000E+01	0.5000E+01
XX27QT2 VALUE	0.2333E+01	0.2055E+01	0.0000E+00	0.5000E+01	0.5000E+01
XX28QT3 VALUE	0.2333E+01	0.2055E+01	0.0000E+00	0.5000E+01	0.5000E+01
XX70	0.3111E+01	0.1100E+01	0.0000E+00	0.4667E+01	0.4667E+01
XX71PERIOD	0.1000E+01	0.0000E+00	0.0000E+00	0.1000E+01	0.1000E+01
XX72VALUE	0.3210E+00	0.4911E-01	0.0000E+00	0.3557E+00	0.2515E+00

3. Validation of Quarter Three (SMCC 5)

POQ Calculation (Qtr 3)

Calculation
$$XX(72) = \sqrt{\frac{(2 * 5.2)}{((14/3) * 1409 * ((.1/12) * 3)}} = 0.25152$$

Note: XX(72) is rounded up to 1. Place an order every month during the quarter. Order quantity is 14/3 or 4.67 units. When rounded, this order quantity is 5 units per month.

Computer Simulation Output (Qtr 3)

S L A M   I I   S U M M A R Y   R E P O R T

****STATISTICS FOR TIME-PERSISTENT VARIABLES****

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	CURRENT VALUE
XX5 ACTUAL	0.4538E+01	0.4881E+01	0.0000E+00	0.1400E+02	0.1400E+02
XX14FCSTDMD	0.5788E+01	0.4642E+01	0.0000E+00	0.1400E+02	0.1400E+02
XX26QT1 VALUE	0.3000E+01	0.2121E+01	0.0000E+00	0.5000E+01	0.5000E+01
XX27QT2 VALUE	0.3000E+01	0.2121E+01	0.0000E+00	0.5000E+01	0.5000E+01
XX28QT3 VALUE	0.3000E+01	0.2121E+01	0.0000E+00	0.5000E+01	0.5000E+01
XX70	0.3500E+01	0.1167E+01	0.0000E+00	0.4667E+01	0.4667E+01
XX71PERIOD	0.1000E+01	0.0000E+00	0.0000E+00	0.1000E+01	0.1000E+01
XX72VALUE	0.3036E+00	0.5209E-01	0.0000E+00	0.3557E+00	0.2515E+00

4. Validation of Quarter Four (SMCC 5)

POQ Calculation (Qtr 4)

Calculation
$$XX(72) = \sqrt{\frac{(2 * 5.2)}{((14/3) * 1409 * ((.1/12) * 3)}} = 0.25152$$

Note: XX(72) is rounded up to 1. Place an order every month during the quarter. Order quantity is 14/3 or 4.67 units. When rounded, this order quantity is 5 units per month.

Computer Simulation Output (Qtr 4)

S L A M   I I   S U M M A R Y   R E P O R T

****STATISTICS FOR TIME-PERSISTENT VARIABLES****

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	CURRENT VALUE
XX5 ACTUAL	0.4631E+01	0.4754E+01	0.0000E+00	0.1400E+02	0.1400E+02
XX14FCSTDMD	0.5354E+01	0.4522E+01	0.0000E+00	0.1400E+02	0.7000E+01
XX26QT1 VALUE	0.3400E+01	0.2059E+01	0.0000E+00	0.5000E+01	0.5000E+01
XX27QT2 VALUE	0.3400E+01	0.2059E+01	0.0000E+00	0.5000E+01	0.5000E+01
XX28QT3 VALUE	0.3400E+01	0.2059E+01	0.0000E+00	0.5000E+01	0.5000E+01
XX70	0.3733E+01	0.1143E+01	0.0000E+00	0.4667E+01	0.4667E+01
XX71PERIOD	0.1000E+01	0.0000E+00	0.0000E+00	0.1000E+01	0.1000E+01
XX72VALUE	0.2932E+00	0.5104E-01	0.0000E+00	0.3557E+00	0.2515E+00

Appendix Q. Verification of the DLA Economic Order Quantity Model

To verify the DLA Economic Order Quantity (EOQ) model, mean values for each SMCC's TBO and QPD were inserted into the respective create nodes of the computer model. The performance of the computer model was verified by running the models for one year and collecting the EOQ value every quarter. This simulation output value was then compared to results that were calculated analytically. Model verification was completed when computer output based on the mean input agreed with first-year analytical results. The analytic calculations and simulation output for the EOQ value are presented below (for this SMCC, TBO was 51 days and QPD was 7 units):

Variables Used to Validate the EOQ Model

Variable	Description
XX(5)	Actual Demand (current quarter)
XX(7)	EOQ Value
XX(14)	Forecasted Demand (next quarter)
XX(15)	Unit price (*v*)
A	Ordering cost
r	Annual holding cost

Formula to Calculate Economic Order Quantity Value

Calculation
$XX(7) = \sqrt{\frac{(2 * A * (XX(5))}{v * ((r / 12) * 3)}}$

1. Validation of Quarter One (SMCC 5)

EOQ Calculation (Qtr 1)

Calculation
$XX(7) = \sqrt{\dfrac{(2 * 5.2 * 7}{1409 * ((.1/12) * 3)}} = 1.4376$

Note: XX(7) is rounded up to 2. Place an order for 2 whenever the inventory level falls to the reorder point.

Computer Simulation Output (Qtr 1)

S L A M   I I   S U M M A R Y   R E P O R T

****STATISTICS FOR TIME-PERSISTENT VARIABLES****

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	CURRENT VALUE
XX5 ACTUAL	0.1538E+01	0.2899E+01	0.0000E+00	0.7000E+01	0.7000E+01
XX7 USERF2 EOQ	0.7191E+00	0.7191E+00	0.0000E+00	0.1438E+01	0.1438E+01
XX14QFD	0.9231E+01	0.4070E+01	0.0000E+00	0.1400E+02	0.1400E+02

2. Validation of Quarter Two (SMCC 5)

EOQ Calculation (Qtr 2)

Calculation
$XX(7) = \sqrt{\dfrac{(2 * 5.2 * 14}{1409 * ((.1/12) * 3)}} = 2.03308$

Note: XX(7) is rounded down to 2. Place an order for 2 whenever the inventory level falls to the reorder point.

Computer Simulation Output (Qtr 2)

S L A M   I I   S U M M A R Y   R E P O R T

****STATISTICS FOR TIME-PERSISTENT VARIABLES****

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	CURRENT VALUE
XX5 ACTUAL	0.3779E+01	0.4740E+01	0.0000E+00	0.1400E+02	0.1400E+02
XX7 USERF2 EOQ	0.9701E+00	0.6831E+00	0.0000E+00	0.2033E+01	0.2033E+01
XX14QFD	0.8293E+01	0.4490E+01	0.0000E+00	0.1400E+02	0.0000E+00

3. Validation of Quarter Three (SMCC 5)

EOQ Calculation (Qtr 3)

Calculation
$XX(7) = \sqrt{\dfrac{(2 \ * \ 5.2 \ * \ 14}{1409 \ * \ ((.1/12) \ * \ 3)}} = 2.03308$

Note: XX(7) is rounded down to 2. Place an order for 2 whenever the inventory level falls to the reorder point.

Computer Simulation Output (Qtr 3)

```
S L A M   I I   S U M M A R Y   R E P O R T
**STATISTICS FOR TIME-PERSISTENT VARIABLES**

                    MEAN          STANDARD      MINIMUM       MAXIMUM       CURRENT
                    VALUE         DEVIATION     VALUE         VALUE         VALUE
XX5 ACTUAL        0.4489E+01    0.4877E+01    0.0000E+00    0.1400E+02    0.1400E+02
XX7 USERF2 EOQ    0.1236E+01    0.7496E+00    0.0000E+00    0.2033E+01    0.2033E+01
XX14QFD           0.7457E+01    0.4651E+01    0.0000E+00    0.1400E+02    0.0000E+00
```

4. Validation of Quarter Three (SMCC 5)

EOQ Calculation (Qtr 4)

Calculation
$XX(7) = \sqrt{\dfrac{(2 \ * \ 5.2 \ * \ 14}{1409 \ * \ ((.1/12) \ * \ 3)}} = 2.03308$

Note: XX(7) is rounded down to 2. Place an order for 2 whenever the inventory level falls to the reorder point.

Computer Simulation Output (Qtr 4)

```
S L A M   I I   S U M M A R Y   R E P O R T
**STATISTICS FOR TIME-PERSISTENT VARIABLES**

                    MEAN          STANDARD      MINIMUM       MAXIMUM       CURRENT
                    VALUE         DEVIATION     VALUE         VALUE         VALUE
XX5 ACTUAL        0.4580E+01    0.4753E+01    0.0000E+00    0.1400E+02    0.1400E+02
XX7 USERF2 EOQ    0.1395E+01    0.7424E+00    0.0000E+00    0.2033E+01    0.2033E+01
XX14QFD           0.6696E+01    0.4697E+01    0.0000E+00    0.1400E+02    0.7000E+01
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Goulet Vita

Captain Wayne C. Goulet was born on 2 February 1964 in Marlboro, Massachusetts. He attended St. John’s High School in Shrewsbury, Massachusetts, graduating in 1982. He enlisted in the Air Force in 1986 as a supply technician. In 1989 he graduated from Nova Southeastern University with a Bachelor of Science degree in Professional Management. In 1991 he graduated from Officer’s Training School with a commission as a second lieutenant.

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